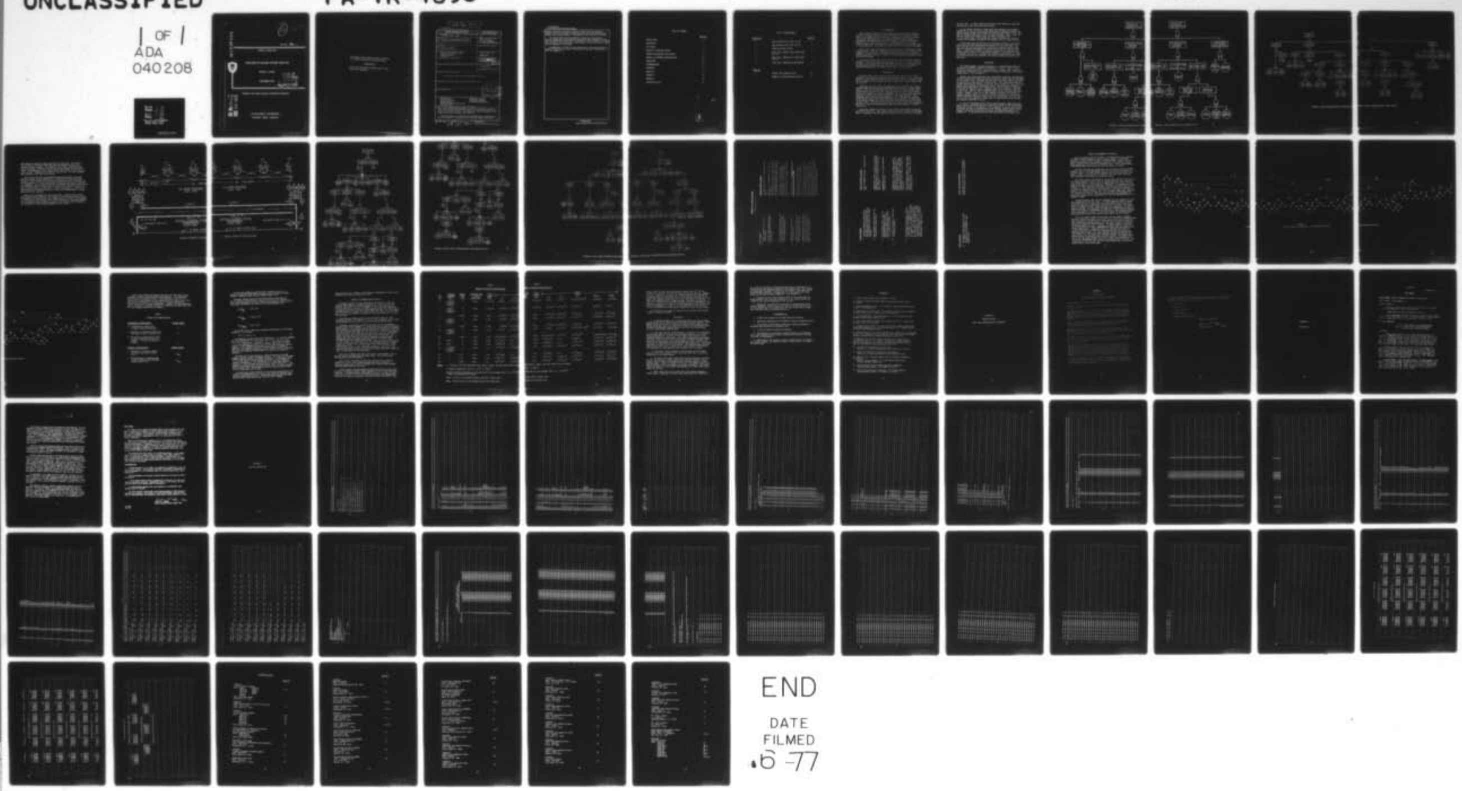
AD-A040 208 PICATINNY ARSENAL DOVER N J F/G 13/12
ANALYSIS OF DELUGE SYSTEM, BULK HE.(U)
DEC 75 W J COFFEY
UNCLASSIFIED PA-TR-4895 NL

1 OF 1
ADA
040208



END
DATE
FILMED
6-77

(11)

ADA040208

COPY NO. 35

TECHNICAL REPORT 4895

# ANALYSIS OF DELUGE SYSTEM, BULK HE


WILLIAM J. COFFEY


DECEMBER 1975



APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED




PICATINNY ARSENAL
DOVER, NEW JERSEY

The findings in this report are not to be construed as an official Department of the Army position.

## DISPOSITION

Destroy this report when no longer needed. Do not return to the originator.

14 PA-TR-4895

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

## REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

| | |
|---|---|
| 1. REPORT NUMBER | Technical Report 4895 |
| 2. GOVT ACCESSION NO. | |
| 3. RECIPIENT'S CATALOG NUMBER | |
| 4. TITLE (and Subtitle) | 6 Analysis of Deluge System, Bulk HE. |
| 5. TYPE OF REPORT & PERIOD COVERED | 9 Final Rep[redacted]t. |
| 6. PERFORMING ORG. REPORT NUMBER | |
| 7. AUTHOR(s) | 10 William J. Coffey |
| 8. CONTRACT OR GRANT NUMBER(s) | |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS | Safety Concepts Branch, NDED<br>Picatinny Arsenal<br>Dover, NJ |
| 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS | ~~A13P424594F1~~ |
| 11. CONTROLLING OFFICE NAME AND ADDRESS | |
| 12. REPORT DATE | 11 Dec[redacted]/[redacted]75 |
| 13. NUMBER OF PAGES | 64 (12) 62p. |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) | |
| 15. SECURITY CLASS. (of this report) | UNCLASSIFIED |
| 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE | |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)



18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Deluge Systems
Fault Tree Analysis
Design Analysis
Computer Programming Fault Trees
Fire Protection
Ultra Violet Sensing
Probability Analysis
Safe Response Prediction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A safety oriented design analysis is described covering an explosion proof, fire detection and protection system for conveyors transporting high explosives at fixed distances. The analysis was made on the system as the design evolved under a separate study contract.

The design analysis was performed in conjunction with a comprehensive Fault Tree Analysis. A preliminary Fault Tree was prepared free hand. → next page

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

CDE 282 904

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

cont

Computer codes were then used to construct a final Fault Tree, determine minimal cut sets, and determine failure probabilities with and without maintenance and/or testing programs. Illustrations of the code work are included.

The initial design indicated ~~(12)~~ twelve single-point failure modes. A means of increasing to two element failure modes has been recommended. Using the same failure rates three orders of improvement can be achieved by this change. Test and repair rates of from one-to-three months are shown to provide an added order-of-magnitude of improvement.

Recommendations on final design of system based on the design analysis and computer results have been made. Additional work and areas of investigation have been suggested.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

## INTRODUCTION

Under Contract DAAA21-74-C-0319, initiated in April 1974, Southwest Research Institute (SwRI) was tasked to design and demonstrate a Deluge System to extinguish fires on conveyors following an accidental dentonation of bulk high explosives. The Safety Concepts Branch, Nuclear Development and Engineering Directorate (ND&ED), Picatinny Arsenal was authorized in October 1974 to perform an independent safety oriented design analysis and apply Fault Tree Analysis techniques to the SwRI design as it was developed. The purpose of this report is to document this work.

Some of the items considered herein may exceed the requirements in the cited contract. However, a comprehensive safety analysis must address all components of the system. Fault Tree Analysis will provide an overall systems approach and serve as a tool for both Engineering Management review and decision making.

Fault Tree Analysis was used to investigate and identify the relationships and causes of the undesired end event "no flow" or "improper flow" of water. Once constructed, the Fault Tree was used to both qualitatively and quantitatively evaluate the entire system. The results identify potential problem areas and their overall impact on the system.

## METHODOLOGY

The basic logic events used for the Fault Tree were the AND and OR occurrences necessary to cause the event directly above it. The AND events must each occur before the next event above will occur. An OR event is any one of a number of events which in itself could cause the next event above it to occur.

Initially, the Fault Tree developed was used to determine the single failure modes which would cause the undesirable end event: Deluge System Failure. Each of the design features was related to the undesired final event working from the top down. Each possible event which could cause failure was itemized in order of occurrence and, in turn, succeeding events necessary to cause each of these events to occur were itemized. Hand developed Fault Trees were then drawn up to help visualize the complete system based on the list of events visible to the analyst. In the review of the Deluge System, two simple trees were drawn up followed by two more detailed trees. The detailed trees contained system changes which appeared desirable in that they presented AND logic failure responses to enhance reliability.

Particular attention was paid to those single events which caused the undesirable end event. Each single point failure was reviewed to determine what, if anything, could be done to require more than one failure to cause

the end event. As these single point failures were developed, they were pointed out to the Contract Project Officer.

In the initial approach to using Fault Tree Analysis, one assumes a probability of one (1) of each event occurring and therefore attempts to present system changes which provide AND response requirements (i.e., more than one failure event must occur) for system failure. Since a chain is only as strong as its weakest link, one must continually look for the weakest link in the system and attempt to provide the simplest solution to strengthen and improve the condition as it is seen to exist.

As the Fault Tree was developed, an associated schematic showing the basic electrical and mechanical configuration was also developed. The Fault Tree was then hand detailed and available computer programs (see Section, Computer Programming and Analysis) were used to draw the Fault Tree. A sensitivity analysis to exercise the system with varying probability rates, based on the engineering judgment of the analyst was used to determine soft spots. Finally, more accurate probability rates, based on failure rate data investigation, and varied testing and repair rates were used.

## DISCUSSION

The design analysis consisted initially of a comprehensive review of the original documents available (reference 1, 2 and 3). Figure 1 was a result of review of documents referenced above. Figure 2 was a result of discussions (reference 4) in response to questions developed in the initial safety review. (See Appendix A)

Briefly, the system consisted of an anti-freeze protected, unpressurized open pipe system with piping and nozzles located at floor level on each side of the conveyor line. Isolation from the main pressurized supply line would be provided by an explosively-activated valve. Valve activation would be provided electrically through a controller which received an input from ultra violet, light sensing, fire detection heads. The controller provides an electrical energy output to an explosive squib which ruptures a diaphragm in the valve. Figure 1 shows a complete series of OR functions, any one of which will cause NO FLOW or IMPROPER FLOW of water, representing system failure. Figure 2 shows two (2) AND functions provided, one through redundant explosive squibs in the valve, wired in parallel; and the second through redundant electrical power, both line and battery. The Fault Tree still shows a large number of single point OR functions which would cause the undesired end event to occur.

As a part of developing their overall design concept, SwRI, under its basic contract, developed and tested separate portions of the final design. During this period of the design, a trip (reference 6) to the contractor's facilities was made to witness some of the testing, further discuss design progress and review any available in-house and manufacturers' data (see Appendix B). Of particular interest were observations of daylight, open

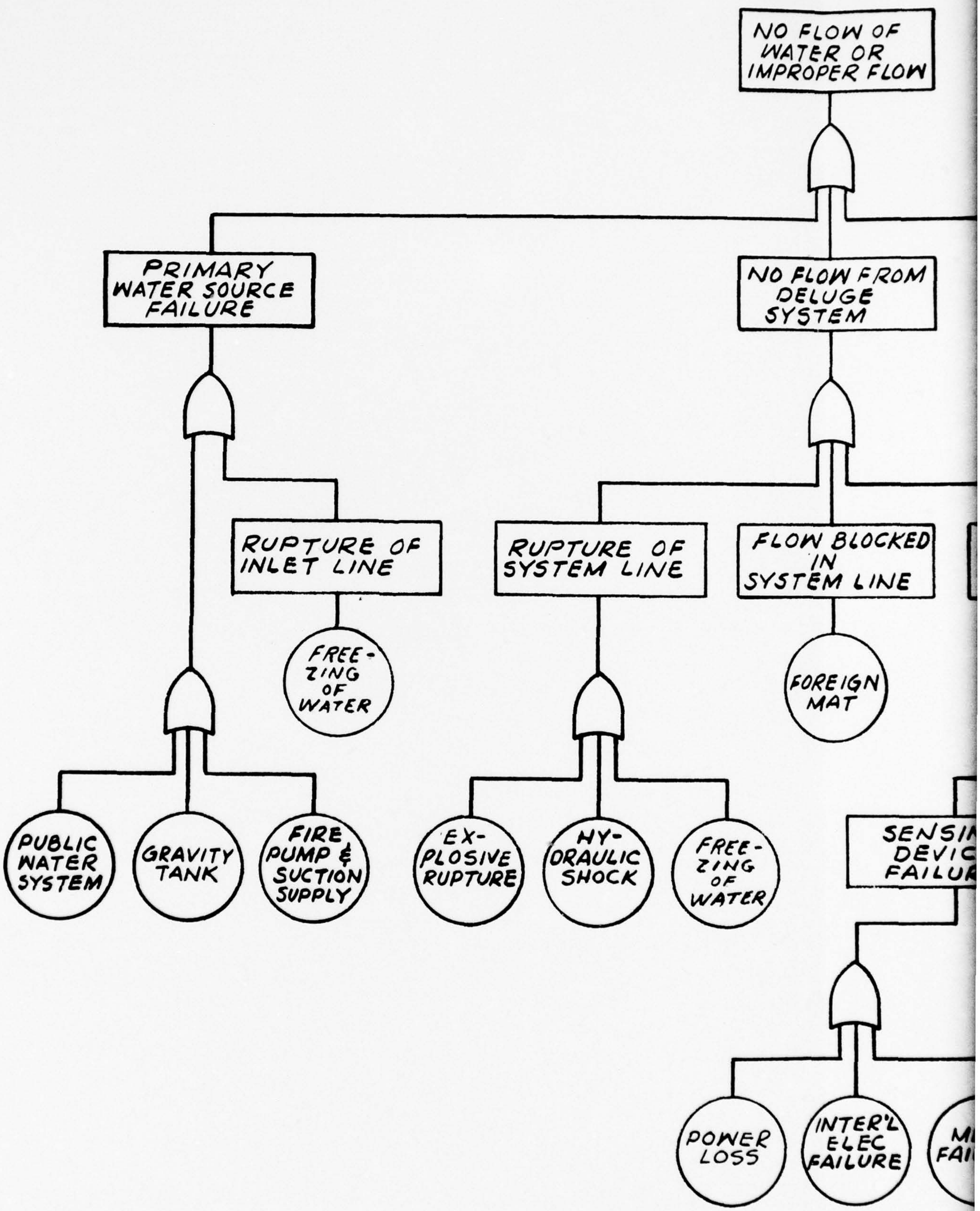





FIGURE 1 HAND DEVELOPED FAULT TREE

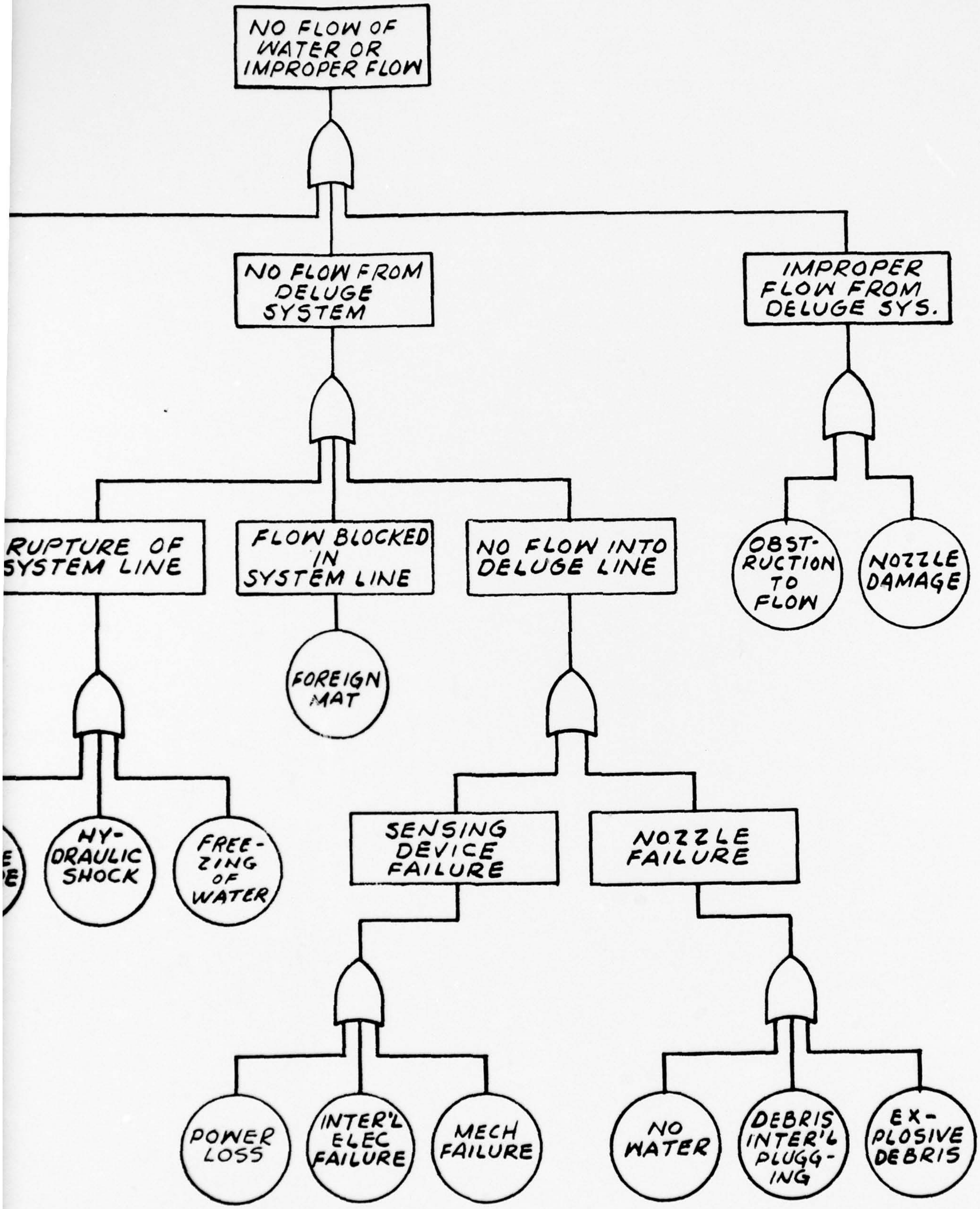





FIGURE 1 HAND DEVELOPED FAULT TREE 1ST CUT

2

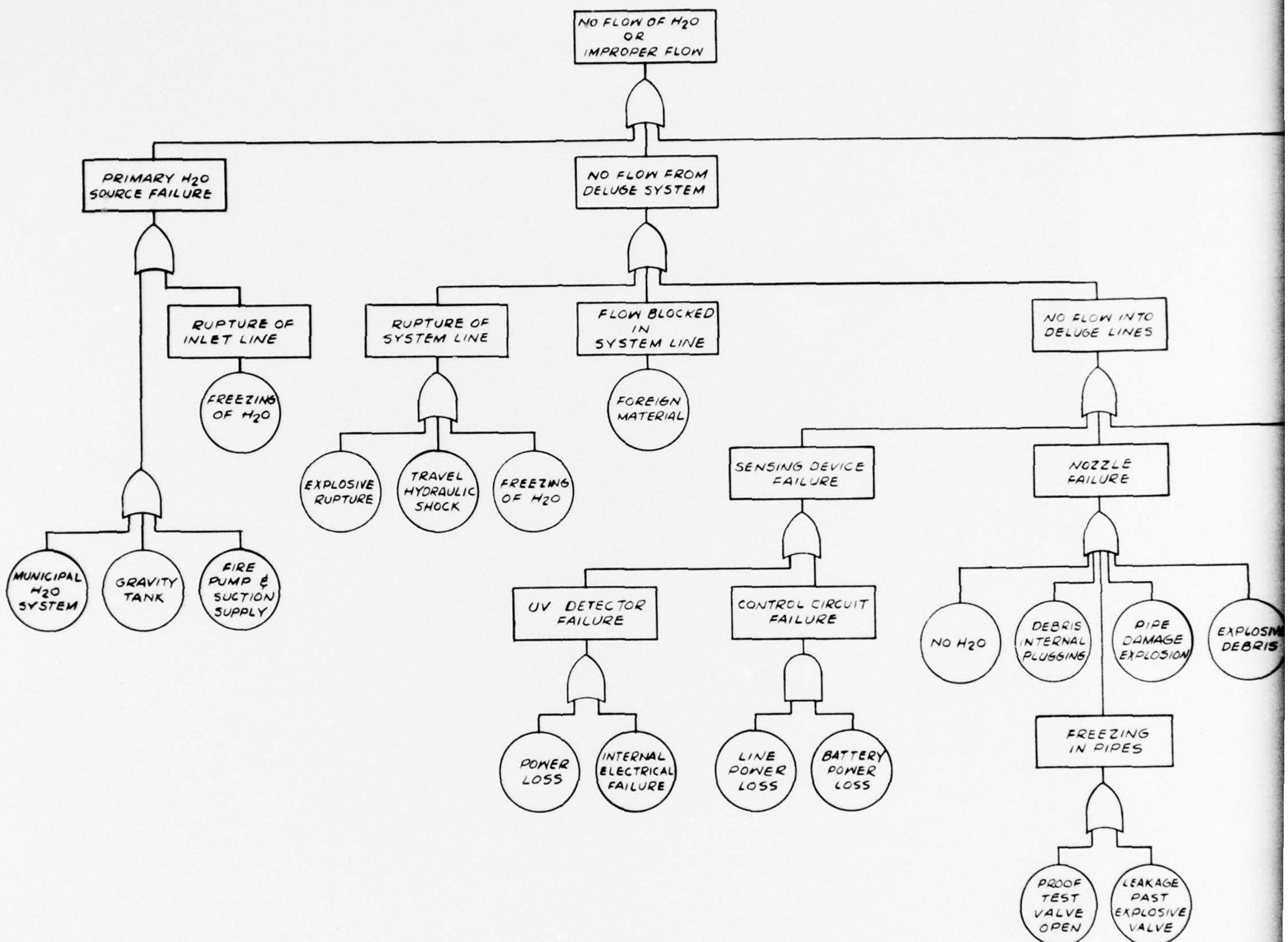
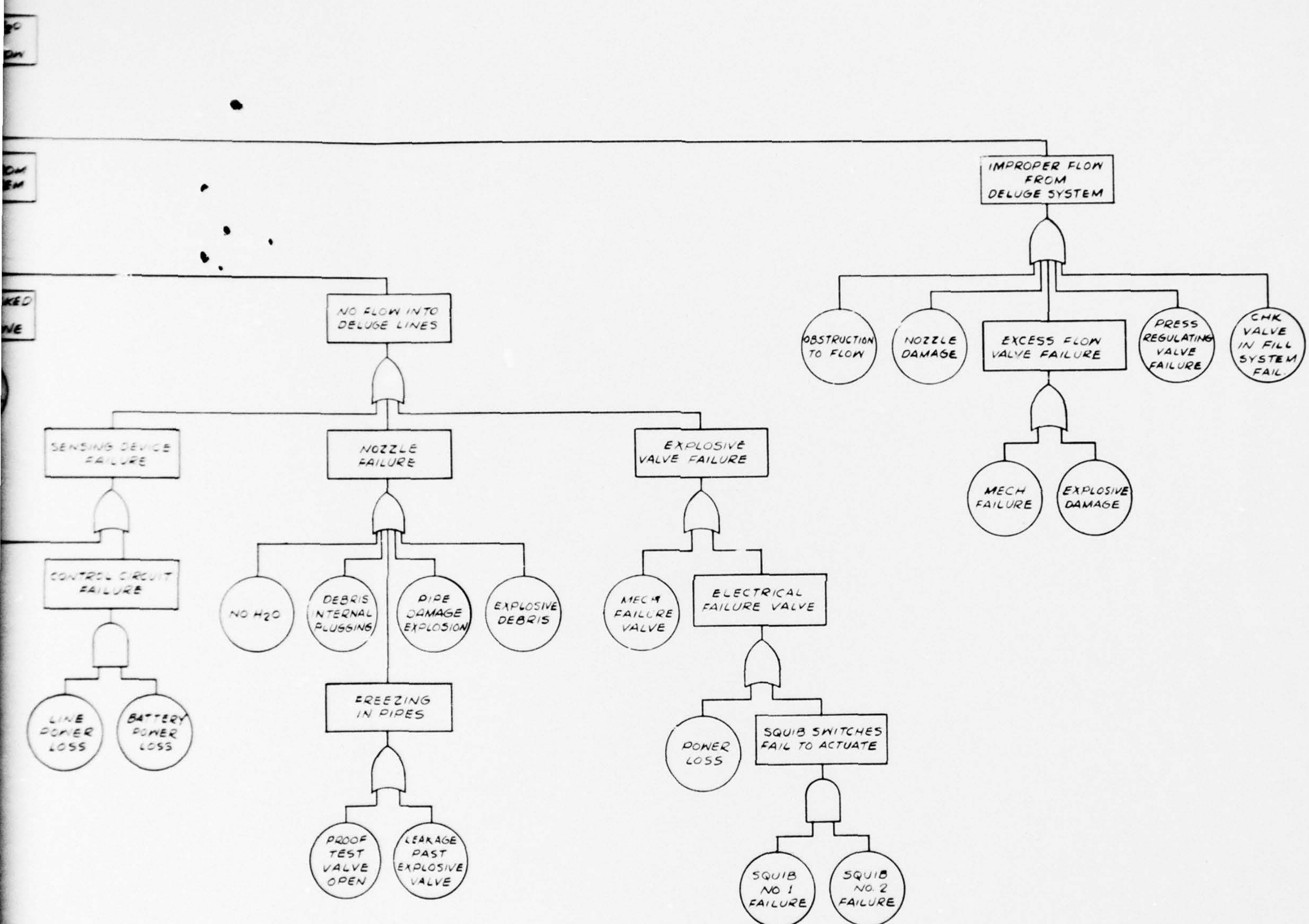



FIGURE 2 HAND DEVELOPED FAULT TREE 2ND CU




IGURE 2 HAND DEVELOPED FAULT TREE 2ND CUT

field ignition testing of small quantities of flake TNT. The response of a UV head to the small flames was good at distances up to 60 feet (maximum distance tested). The flame was deep orange, relatively mild, and slow burning. Combustion occurred with large amounts of heavy black smoke. Extinguishment of the flame occurred very rapidly in the order of a few seconds. Sunlight had no effect on the UV head. It only responded when ignition of the Flake TNT occurred.

The analysis took into consideration observations made on the flake TNT fire testing at SwRI (reference 6), acquisition and review of manufacturer's data; discussions with Detector Electronics Corp. (reference 7), one manufacturer of UV response systems; discussions with Grinnel Sprinkler Co. regarding a black powder installation at Indiana Army Depot (reference 8); and discussions with Lea Engineering of Pittsburg on a Bureau of Mines program covering methane gas explosions in mines (reference 9). A search of the literature for alternate means of control and extinguishment in Deluge Systems was also conducted.

Based on all considerations mentioned above, a study of the possible basic piping layout variations and a study of UV head spacing and coverage, a Schematic of a proposed base line design (Figure 3) and two (2) iterations of a final Fault Tree (Figures 4 and 5) were developed. The design analysis and the computer program analyses, applied to the design shown in Figure 3, are covered in the succeeding paragraphs of this report.

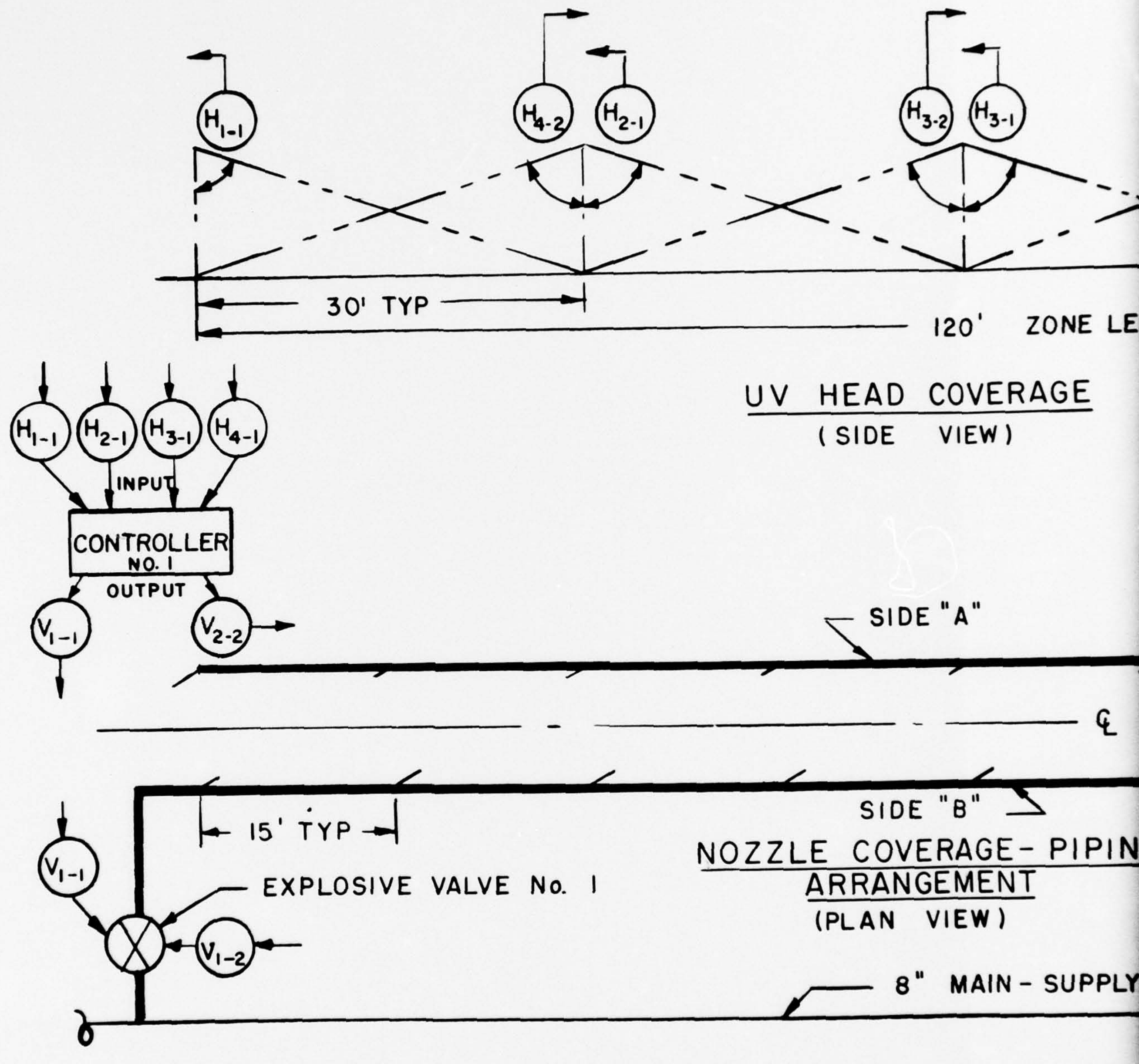



FIGURE 3 SCHEMATIC-DELUGE S

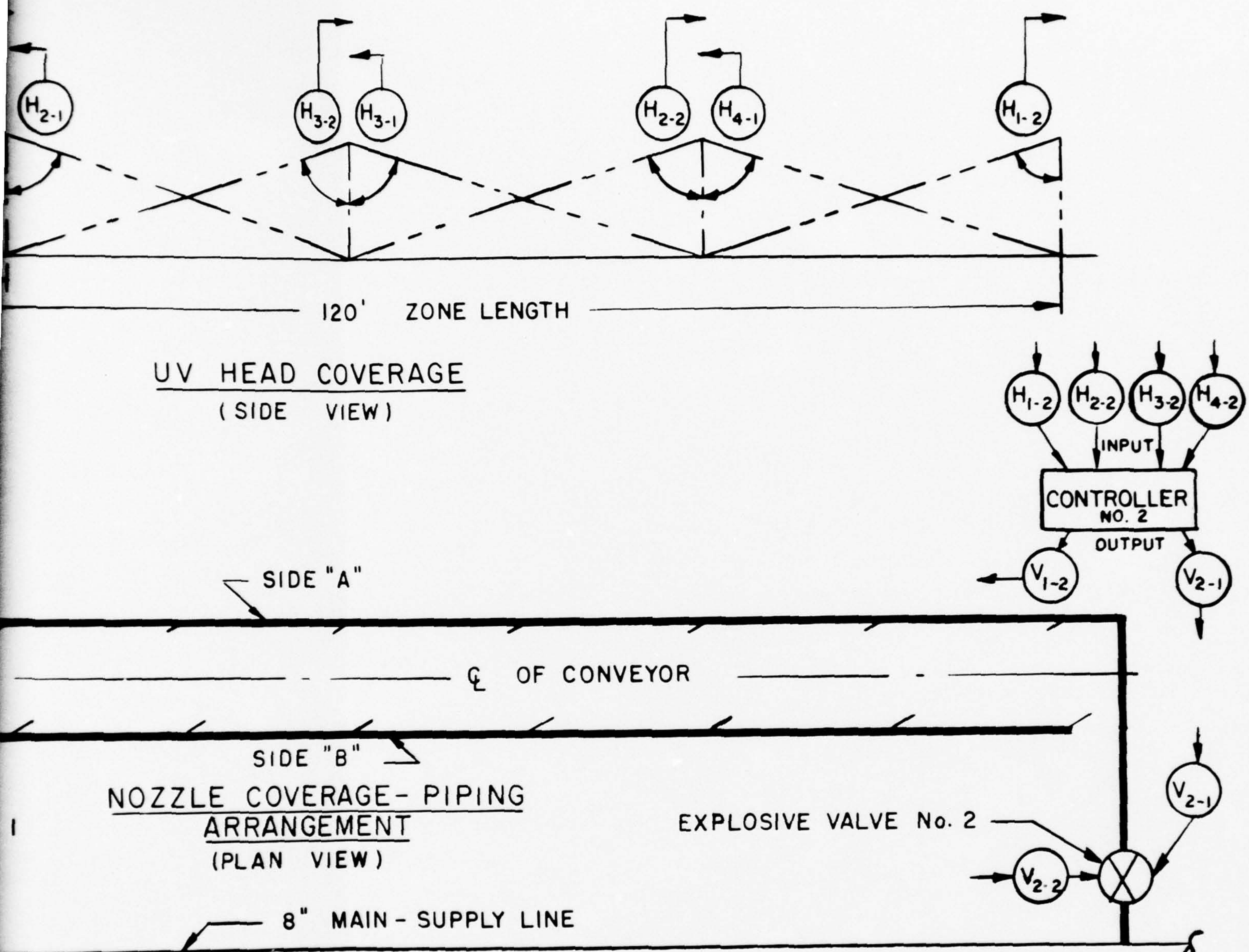
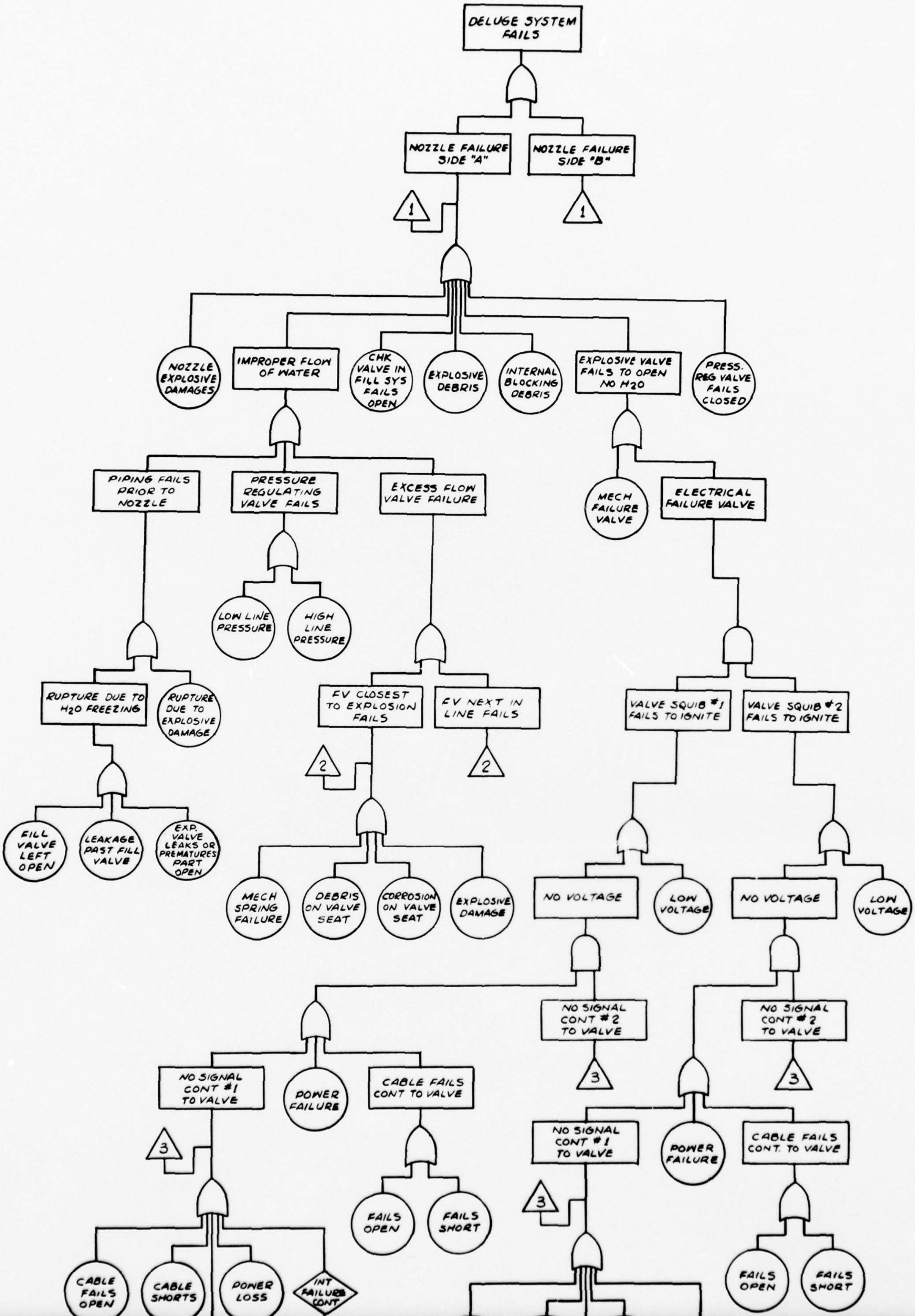



FIGURE 3 SCHEMATIC-DELUGE SYSTEM



2


DELUGE SYSTEM FAILS
NOZZLE FAILURE SIDE "A"
NOZZLE FAILURE SIDE "B"
1
1
NOZZLE EXPLOSIVE DAMAGES
IMPROPER FLOW OF WATER
CHK VALVE IN FILL SYS FAILS OPEN
EXPLOSIVE DEBRIS
INTERNAL BLOCKING DEBRIS
EXPLOSIVE VALVE FAILS TO OPEN NO H2O
PRESS. REG VALVE FAILS CLOSED
PIPING FAILS PRIOR TO NOZZLE
PRESSURE REGULATING VALVE FAILS
EXCESS FLOW VALVE FAILURE
MECH FAILURE VALVE
ELECTRICAL FAILURE VALVE
LOW LINE PRESSURE
HIGH LINE PRESSURE
RUPTURE DUE TO H2O FREEZING
RUPTURE DUE TO EXPLOSIVE DAMAGE
FV CLOSEST TO EXPLOSION FAILS
FV NEXT IN LINE FAILS
2
2
VALVE SQUIB #1 FAILS TO IGNITE
VALVE SQUIB #2 FAILS TO IGNITE
FILL VALVE LEFT OPEN
LEAKAGE PAST FILL VALVE
EXP. VALVE LEAKS OR PREMATURES PART OPEN
MECH SPRING FAILURE
DEBRIS ON VALVE SEAT
CORROSION ON VALVE SEAT
EXPLOSIVE DAMAGE
NO VOLTAGE
LOW VOLTAGE
NO VOLTAGE
LOW VOLTAGE
NO SIGNAL CONT #2 TO VALVE
NO SIGNAL CONT #2 TO VALVE
3
3
NO SIGNAL CONT #1 TO VALVE
POWER FAILURE
CABLE FAILS CONT TO VALVE
3
NO SIGNAL CONT #1 TO VALVE
POWER FAILURE
CABLE FAILS CONT. TO VALVE
3
FAILS OPEN
FAILS SHORT
CABLE FAILS OPEN
CABLE SHORTS
POWER LOSS
INT FAILURE CONT
FAILS OPEN
FAILS SHORT

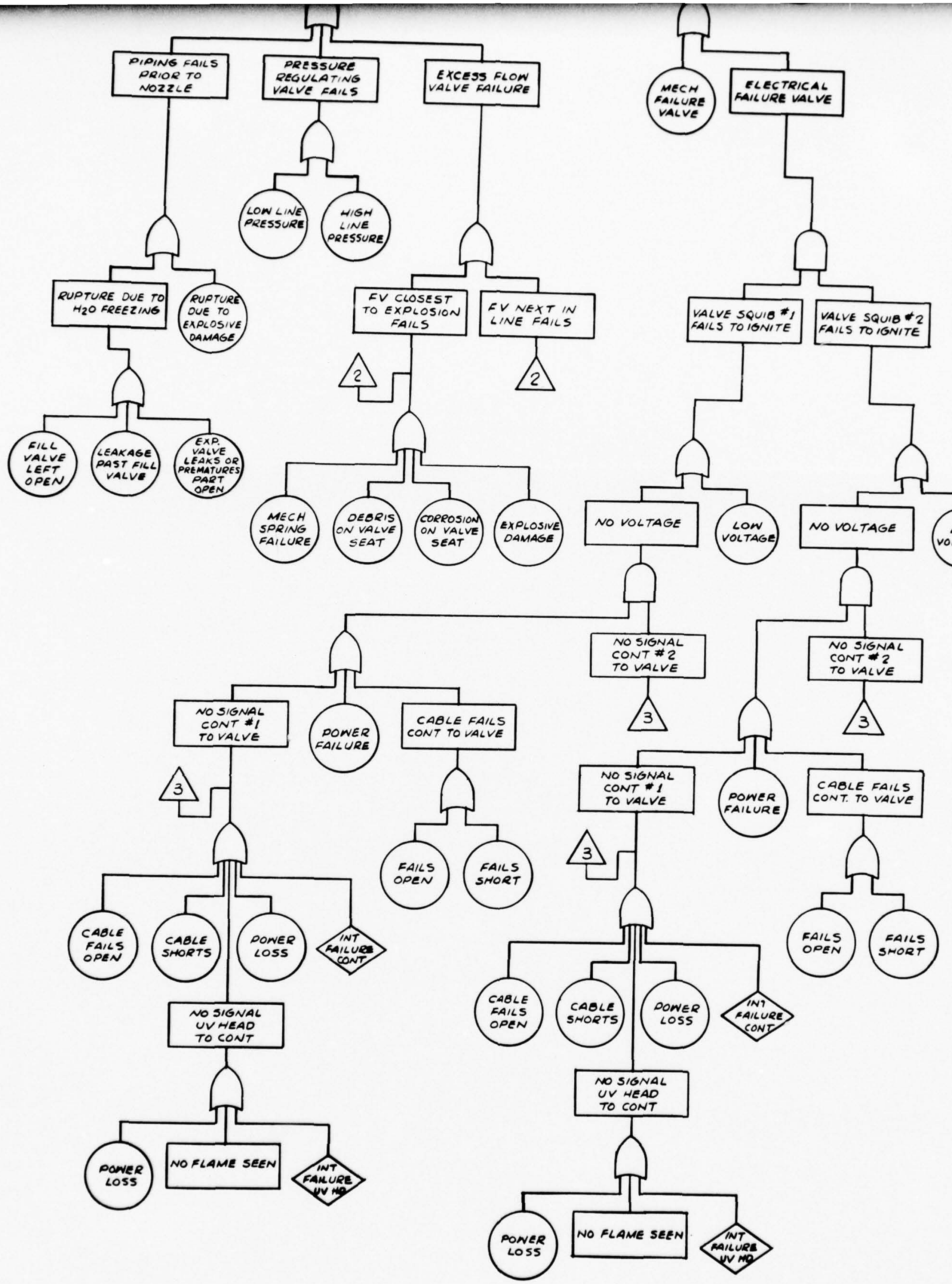



FIGURE 4 FAULT TREE, PROPOSED BASE LINE DESIGN 1ST CUT

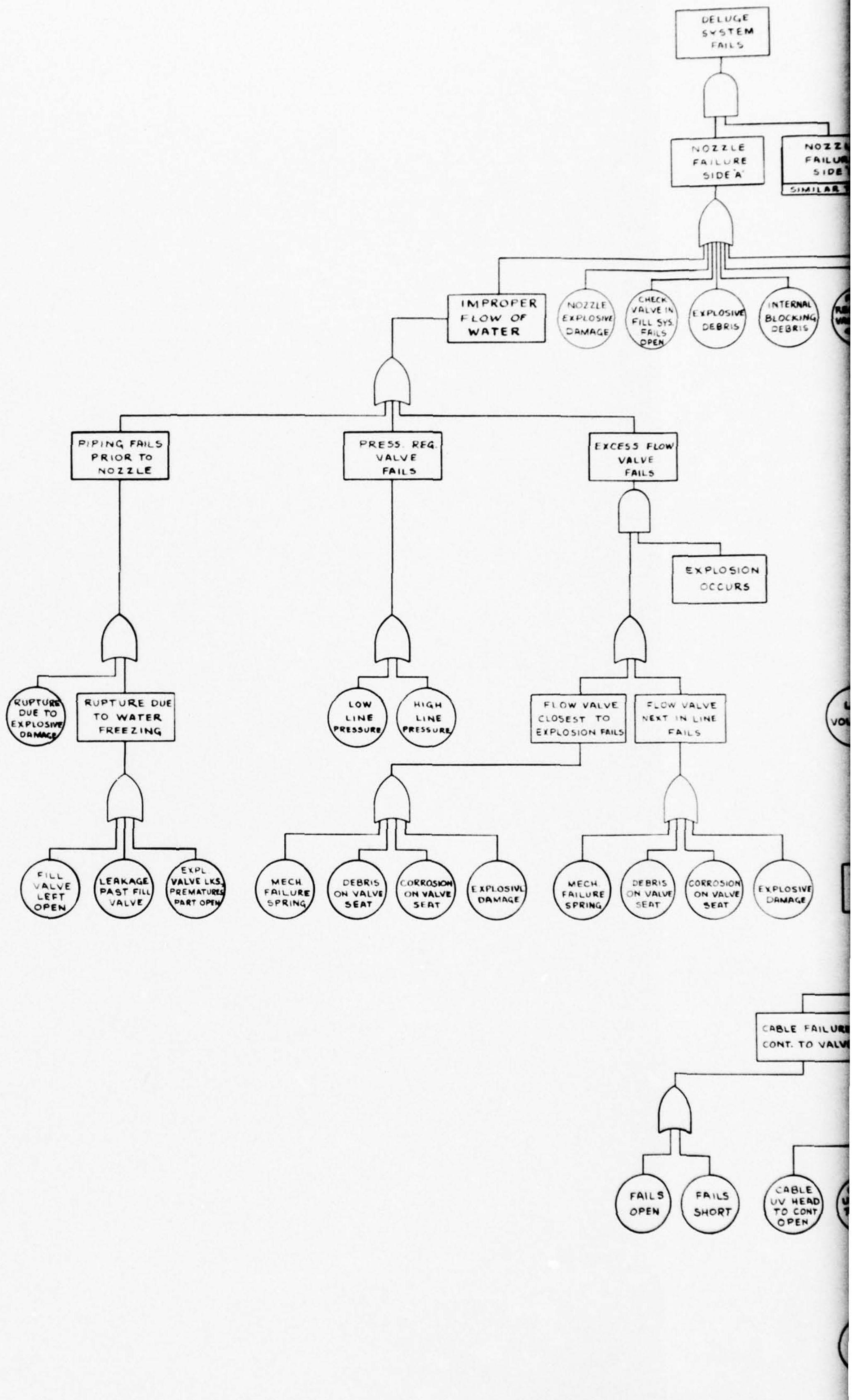



FIGURE 5 FAULT TREE, PROPOSED BASE LINE

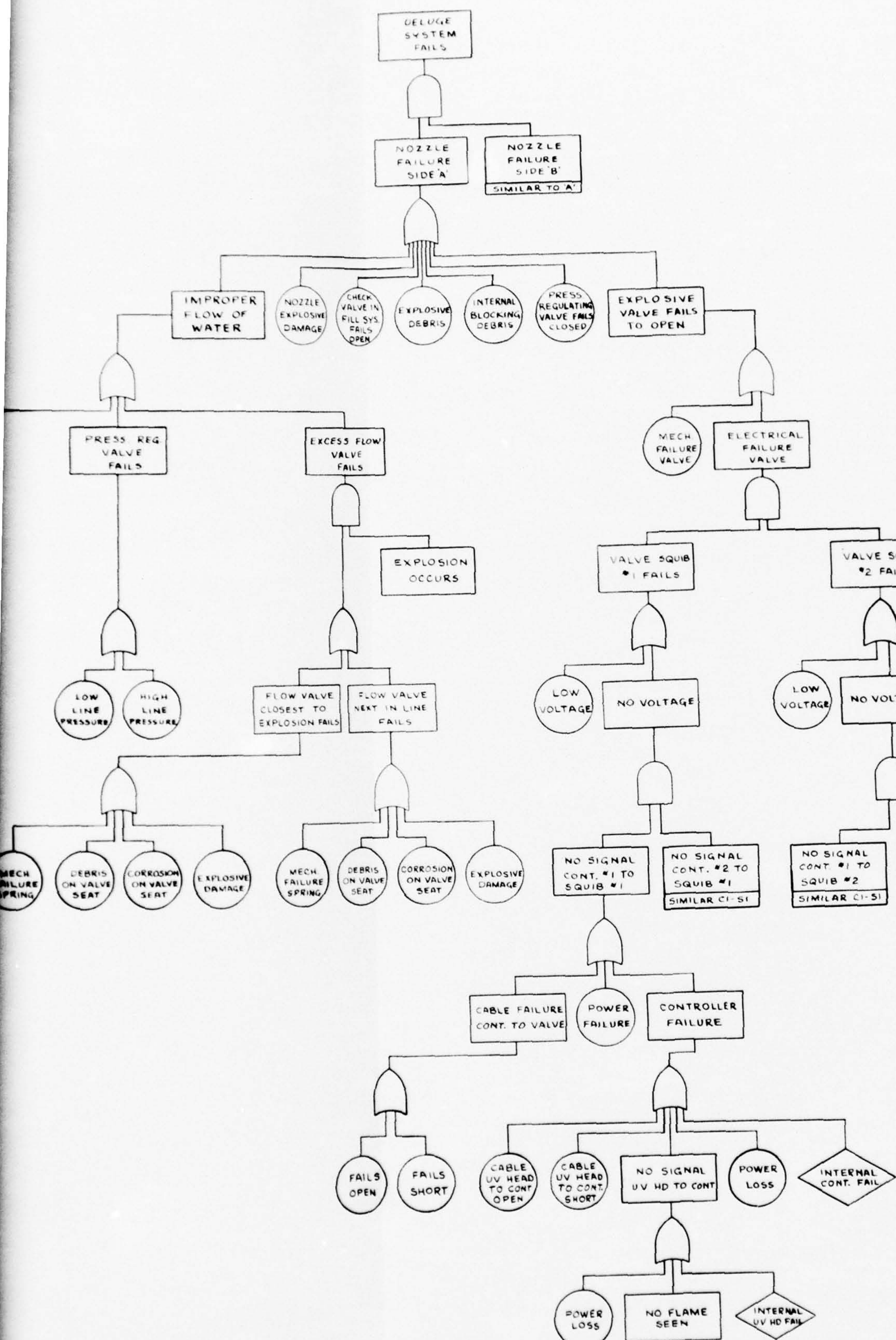



FIGURE 5 FAULT TREE, PROPOSED BASE LINE DESIGN 2ND CUT

2

## ANALYSIS OF BASELINE DESIGN

(Reference Figure 3)

| DESIGN FEATURE | BASIS FOR DESIGN FEATURE |
|---|---|
| 1. Thirty foot (30') spacing of UV sensing heads. | UV head manufacturer's recommended maximum spacing. |
| 2. Each 30' area covered by two (2) UV heads, viewing from opposite ends of area. | Manufacturer recommends two (2) heads on each area. The Safety Concepts Branch (SCB) recommends maximum distance from each other to minimize explosives effects. Would also provide recommended ANDing failure requirement. |
| 3. Two (2) controllers wired in a way such that the two (2) UV heads, covering a given area, are hooked up to a separate controller. | Recommended by SCB to provide ANDing failure response. Based on zone size shown in Figure 3, a second controller would be required, due to manufacturer's limitation of eight (8) heads per controller. |
| 4. Controllers to be solid state, fast response type. | Recommended by SwRI and **Manufacturer to accomplish minimum response time.** |
| 5. Sprinkler spacing shall be on 15' centers or less and limited to 8-10 sprinklers per branch line. | National Fire Protection Association, National Fire Codes, Vol. 6, 1972-73 classified as extra hazard occupancy. |
| 6. Sprinklers located at floor level, or close thereto, and provided with necessary explosive protection. Nozzles shall form small angle with center line of supply pipe. | SwRI recommends location at floor level as least susceptible to explosive damage. SwRI recommends explosive protection of nozzle locations with piping in between, designed to sustain explosive action. Small angle necessary to cover narrow conveyor areas under consideration. Will also provide water coverage of conveyors at a maximum distance from explosive exposure. |

| DESIGN FEATURE | BASIS FOR DESIGN FEATURE |
|---|---|
| 7. A line of sprinklers provided on each side of the conveyor system such that either line would provide the recommended quantity of water coverage. | SwRI recommended design - concurred in by SCB. |
| 8. Each sprinkler line shall have its own explosive deluge valve. | Recommended by SCB to provide a desirable ANDing protection including reduced explosive hazard due to location at opposite ends of zone. |
| 9. Each explosive valve cross connected electrically so that function of either controller will provide activating voltage to both explosive valves. | Recommended by SCB to provide desirable ANDing protection. |
| 10. Wiring of UV heads to controllers in parallel hook-up. | Recommended by SCB to reduce explosive damage effects, based on SwRI tests and discussions with Lea Engineering re Bureau of Mines application. UV heads tested up to 60' by SwRI. Pulses from heads sensing same flame are additive at controller. |
| 11. The nominal piping zone is limited by the number of sprinklers per branch line. The nominal zone length per controller is limited to eight (8) UV heads. Since the UV spacing may be twice that of the sprinkler heads, two controllers could handle a total conveyor length of 240'. A series of eight (8) sprinklers on 15' spacing will handle a length of 120'. | SCB recommended schematic layout; Figure 3 shows a typical 120' zone. SwRI survey indicates length of conveyors run up to approximately 500'. |

| DESIGN FEATURE | BASIS FOR DESIGN FEATURE |
|---|---|
| 12. The manual anti-freeze fill items, not shown on the schematic, are expected to be included in each branch line. | Considered by SCB in Fault Tree analysis. Final SwRI piping layout not available. |

## COMPUTER PROGRAMMING AND ANALYSIS

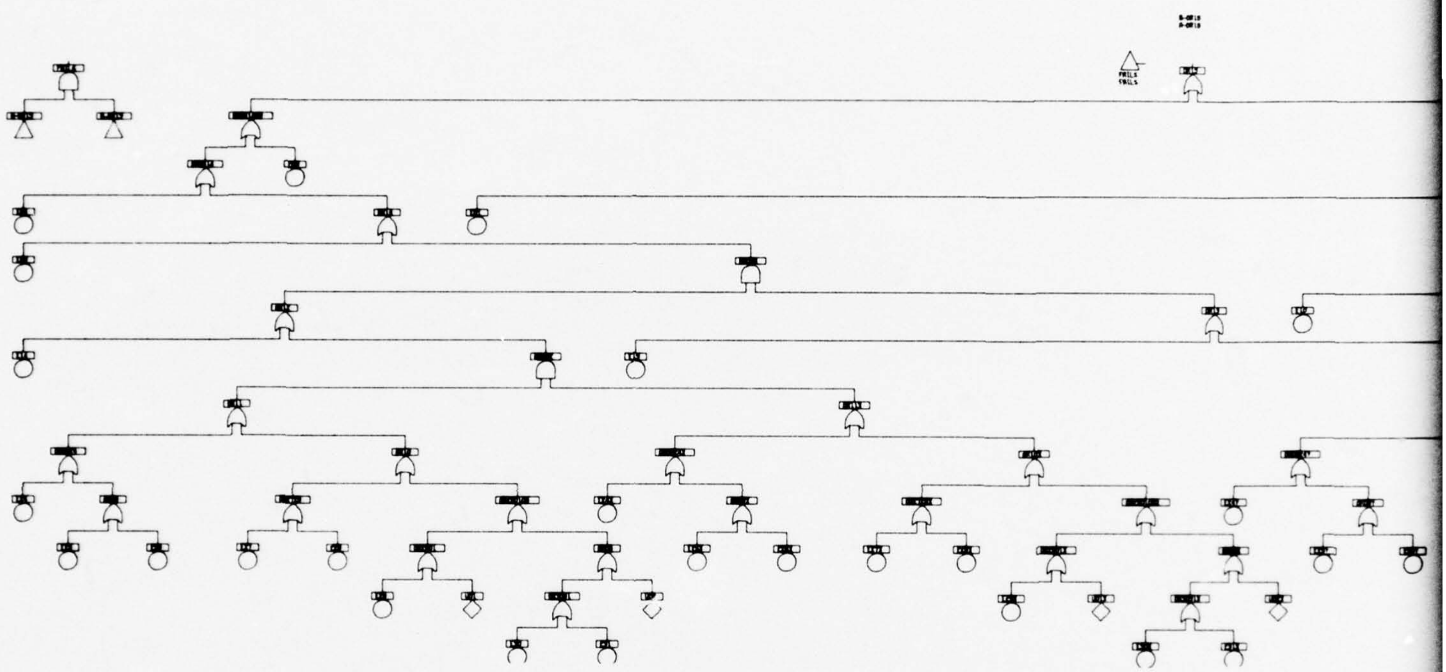
Using the Schematic shown in Figure 3, and final Fault Tree iterations developed as shown in Figures 4 and 5, several computer programs were employed to perform further analysis of the Fault Tree. Each of the programs referenced herein was previously inputed to the computer on other study programs and is available on permanent file. A basic understanding of CDC-6600 SCOPE control cards and file processing is required.

The SETS (reference 10) program was used to record, in proper computer language, each of the Deluge System Fault Tree AND and OR Gate events, inputs and outputs. The SETS program requires that all hand developed tree GATES, of three or more inputs, be reduced to two input logic GATES and then recombined to accomplish the equivalent logic.

The second program, implemented on the CDC 6600, was FTD (reference 11). The program produces a control tape for drawing the Fault Tree on an off-line CalComp Plotter. Due to built-in program limits on overall width and height adjustment, some difficulty was experienced. The program was first modified to remove the width limitation. The resultant Fault Tree is shown in Figure 6. The input data was modified again to use the maximum plot height on the CalComp Plotter. The result is a more legible tree which can be used as an effective working tool. It is somewhat cumbersome, however, for inclusion in a report. Once the Fault Tree has been programmed and proven out, changes can be easily made and a new tree drawing plotted in a minimum of time.

Computer programs PREP and KITT (reference 12) were employed for automatic evaluation of the Fault Tree. The PREP program was used to obtain the minimal cut sets of the Fault Tree, and the KITT program was used to obtain the numerical probabilities associated with the tree. PREP determines the minimal cut sets, either by Monte Carlo simulation or by determination testing. KITT determines the numerical probabilities by means of Kinetic Tree Theory, a methodology by which exact, time dependent probabilistic information is obtained. In the KITT program, non-repairability or maintenance and testing, and constant repair times, can be evaluated.

The basic events (causes) of the Fault Tree are termed "component failures", and the top event of the Fault Tree is termed the "system failure". Once constructed, the Fault Tree is first evaluated to obtain the unique modes by which the system failures can occur and, secondly, to obtain the associated probability characteristics. The unique modes of occurrence are termed minimal cut sets. A cut set is formally defined as any set of system components which when simultaneously failed cause the system to be in the failed state. A minimal cut set is a smallest group (set) of component failures which must all simultaneously exist in order for a system failure to exist. Any other component failures may coexist with this smallest set, but these other component failures are entirely redundant and do not directly cause the system failure. The finite collection of all the unique minimal cut sets of a Fault Tree represents all the unique, nonredundant ways by which the system failure can occur. The system failure can only occur by one of these unique ways or by various combinations of these unique ways.



**FAU**

1

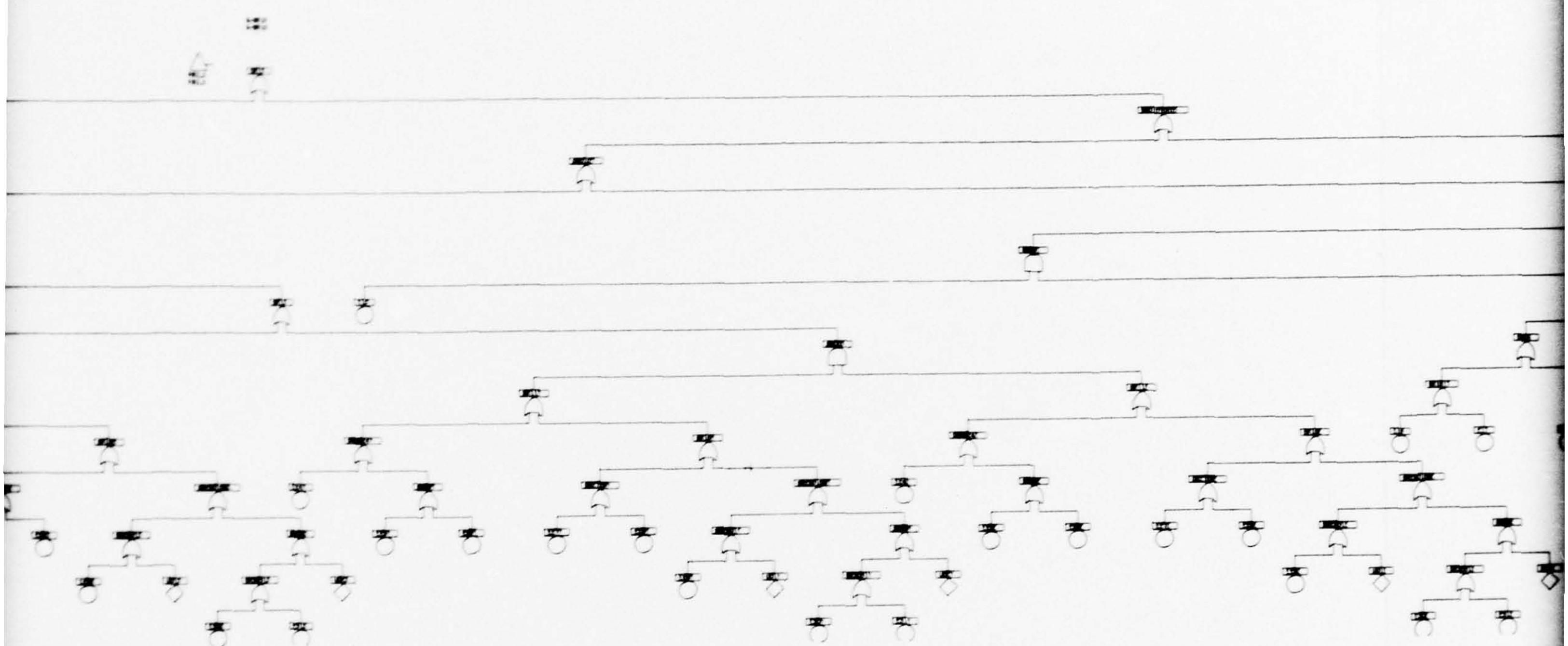


FIGURE 6
FAULT TREE, COMPUTER - CALCOMP PLOTTER



2

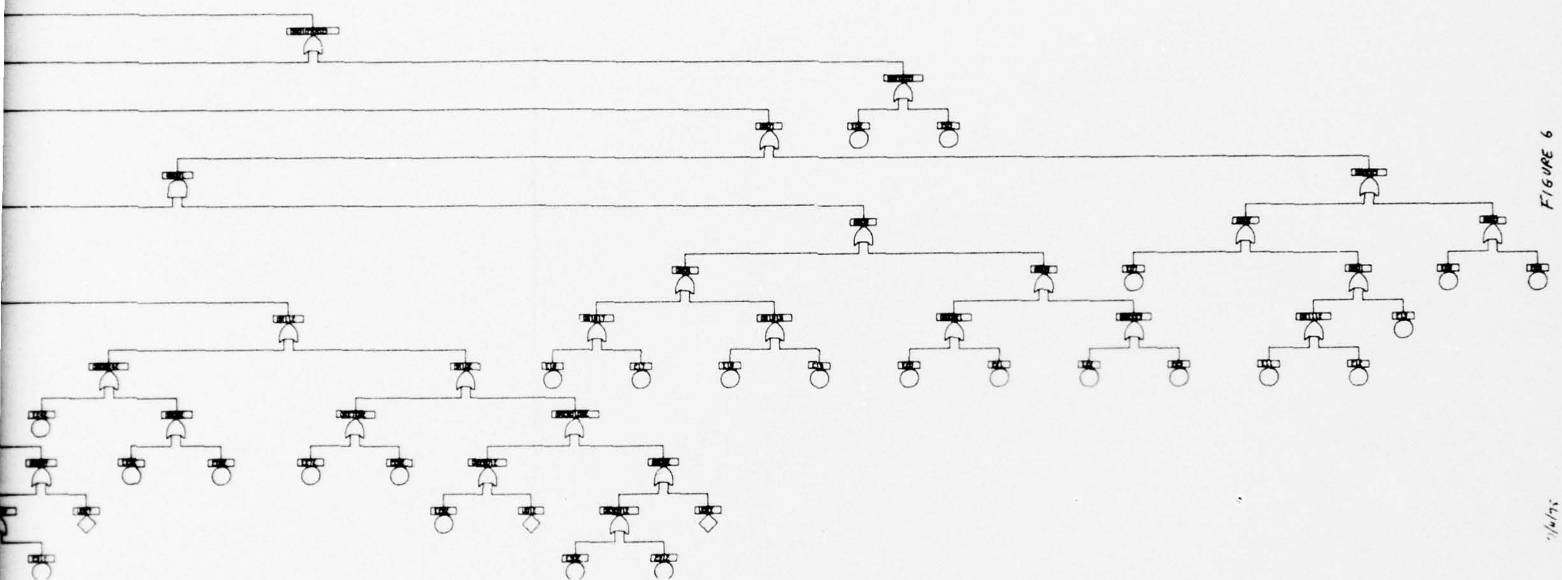


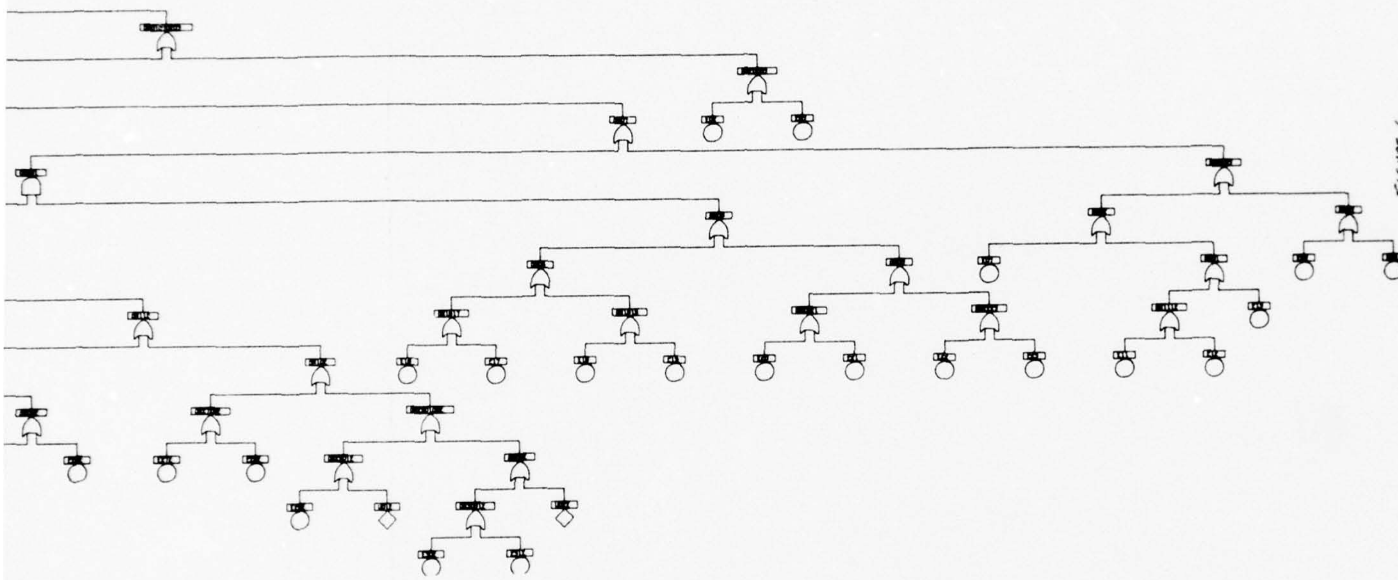
FIGURE 6

CALCOMP PLOTTER

2

3

FIGURE 6



P PLOTTER

After having obtained the minimal cut sets, the Fault Tree is then evaluated to obtain the probability characteristics. The probability characteristics, outlined in Table 1, are obtained not only for the System, but for each minimal cut set identified in the Fault Tree. From this detailed information, the importance of various components and minimal cut sets can be simply ascertained. Moreover, the characteristics may be obtained for any given intervals of operating time (mesh size) over the total elapsed time period of interest.

TABLE 1

PROGRAM DATA IDENTIFICATION

| DIFFERENTIAL CHARACTERISTICS | PROGRAM SYMBOL |
|---|---|
| 1. Probability of failed state at time t (Failed Probability) | Q |
| 2. Expected # of failures suffered per unit time at time t (Failure Rate) | W |
| 3. The failure intensity with respect to time t (Failure Intensity), i.e., Lambdas ( $\lambda$'s) for cut sets and systems | L |

| INTEGRAL CHARACTERISTICS | PROGRAM SYMBOL |
|---|---|
| 1. Expected # of failures suffered during the time interval from o to t | $W_{sum}$ |
| 2. The probability of suffering one or more failures during the time interval from o to t | $F_{sum}$ |

To obtain the probability characteristics defined in Table 1, in addition to the Fault Tree itself, one must provide as input, the probability of component failure per hour (failure rate) P (T).

Initially, failure rates were arbitrarily chosen on the basis of one (1) failure in three months, 1 year, and 2-1/2 years and assigned to those events determined to be most likely, likely, and least likely to occur. Using these time periods the values of P(T) were determined to be:

$$P(T) = \frac{1}{2160} = 463 \times 10^{-6}$$

$$P(T) = \frac{1}{7200} = 138.9 \times 10^{-6}$$

$$P(T) = \frac{1}{21600} = 46.3 \times 10^{-6}$$

The failure rate is related by exponential distribution to the failure intensity ( $\lambda$) as follows:

$$P(T) = 1 - \exp(-\lambda T) \qquad (1)$$

From equation (1), above, the failure intensities ( $\lambda$'s) for each component were then determined to be of the order $4.63 \times 10^{-4}$, $1.38 \times 10^{-4}$, and $4.63 \times 10^{-5}$ respectively. (See Table 2, Run 3.) The failure intensity ( $\lambda$) of each component is assumed to be constant with respect to time. Further, all the components are assumed to be in their operating state at time zero. The component failures on the Fault Tree are assumed independent; any component failure may occur at numerous places on the Fault Tree, but those component failures which are distinct are assumed independent.

The Fault Tree is first input in a simple coded form to the PREP computer program to obtain the minimal cut sets. The output from the PREP program, with the addition of failures intensities ( $\lambda$) and repair rates ( $\tau$), is then input to the KITT program to obtain the time dependent, numerical probabilities. The KITT program is a single phase component program; i.e., each component may have only one failure intensity $\lambda$. The program may be applied with and without repair times $\tau$ for each component. Only one repair rate $\tau$ may be used for the total elapsed operation time (or be non-repairable for all time).

The differential characteristics and the integral characteristics are obtained for each minimal cut set and the full system at operating time intervals specified by the user. Differential characteristics are pointwise quantities, being obtained <u>at</u> a point in time. Integral

characteristics are a summation of failures or probabilities of one or more failures over a period of time from o to t.

## SUMMARY OF COMPUTER PROGRAM RESULTS

A total of sixteen (16) runs were made on the computer. Three (3) used the PREP program to determine the minimal cut sets, and setup the required input data to the KITT-1 program. Since a major AND function occurs at the top of the tree, the effects on the system were determined by comparing one half of the tree to the ANDed full tree. The PREP program produced a series of twelve (12) single-element cut sets for the half tree and a series of one hundred and forty four (144) two-element cut sets for the full tree.

The balance of thirteen (13) runs used the KITT-1 program. Runs identified in Table 2 by numbers 3, 4, 5, 6, 7 and 11 were on the half tree and run numbers 9, 10, 12, 13, 14, 15 and 16 were on the full tree.

Initially a sensitivity analysis of the half tree was programmed to determine the smallest lambdas ( $\lambda$ ) values necessary to show an acceptable system response. An acceptable system response was defined as one in which the system $W_{sum}$ and $F_{sum}$ were both less than one (1), preferably closer to .01, for the total time frame of 2-1/2 and 3 years. Based on the initially assumed values of P(T), probability of failure per hour, the appropriate values of lambdas were calculated and used in the KITT program. The lambdas were then varied by one order-of-magnitude in each category. No testing and repair, or testing and repair rates of six months were arbitrarily used to determine their effect. Runs 3, 4 and 5, using $\lambda$ 's of $4.68 \times 10^{-4}$, $1.38 \times 10^{-4}$ and $4.63 \times 10^{-5}$, did not produce an acceptable response as defined above. Runs 6 and 7, which used two orders of magnitude change, i.e., $\lambda$ 's of $4.63 \times 10^{-6}$, $1.38 \times 10^{-6}$ and $4.63 \times 10^{-7}$, produced $W_{sum}$ and $F_{sum}$ values considered acceptable. The use of a six month test and repair rate in run 7 does not indicate sufficient change over run 6 to merit use of a six month rate.

Runs 9 and 10 employed the full tree using the same lambdas as Run 3, with and without six-month test and repair rates. The resulting $W_{sum}$ and $F_{sum}$ values were unacceptable.

Runs 11 and 12 exercised the half tree and full tree at constant lambdas of $1 \times 10^{-7}$. Both produced results which were acceptable. A comparison between Runs 11 and 12 indicates two to three orders-of-magnitude improvement with the full tree.

A final review of the probability of failure rates P(T) of each event was made to determine lambdas values considered to be most reasonable and practical. From data available (references 13 and 14), a range of failure rates from $15 \times 10^{-6}$ to $8.8 \times 10^{-8}$ appears reasonable. Increasing these values by two orders-of- magnitude, to assure conservatism, failure rates

TABLE 2

SUMMARY OF COMPUTER PROGRAM RESULTS

| RUN # | FAILURE INTENSITY ( $\lambda^{+}$ ) | REPAIR TIME ( $\tau$ ) | OPERATING TIME INTERVAL (MESH SIZE) | TOTAL ELAPSED TIME | Q | W |
|---|---|---|---|---|---|---|
| 3 | $4.63\text{x}10^{-4}$<br>$1.38\text{x}10^{-4}$<br>$4.63\text{x}10^{-5}$ | 0 | 6 mos. | 2 1/2 yrs | $9.9^{-1}/1$ | $2.1^{-3}/.11^{-}$ |
| 4 | $4.6\text{x}10^{-5}$<br>$1.38\text{x}10^{-5}$<br>$4.63\text{x}10^{-6}$ | 0 | 6 mos. | 2 1/2 yrs | $3.8^{-1}/9.9^{-1}$ | $2.2^{-4}/1.0^{-}$ |
| 5 | " | 6 mos. | 3 mos. | 3 yrs | $3.8^{-1}/5.9^{-1}$ | $2.2^{-4}/1.9^{-}$ |
| 6 | $4.6\text{x}10^{-6}$<br>$1.38\text{x}10^{-6}$<br>$4.63\text{x}10^{-7}$ | 0 | 3 mos. | 3 yrs | $4.6^{-2}/4.3^{-1}$ | $2.2^{-5}/2.1^{-}$ |
| 7 | " | 6 mos. | 3 mos. | 3 yrs | $4.6^{-2}/9.0^{-2}$ | $2.2^{-5}/2.2^{-}$ |
| 9 | $4.63\text{x}10^{-4}$<br>$1.38\text{x}10^{-4}$<br>$4.63\text{x}10^{-5}$ | 0 | 3 mos. | 3 yrs | $9.9^{-1}/1$ | $7.7^{-3}/1.7^{-}$ |
| 10 | " | 6 mos. | 3 mos. | 3 yrs | $9.9^{-1}/1/9.9^{-1}/1$ | $7.7^{-3}/7.2^{-}$ |
| 11 | $1\text{x}10^{-7}$ | 0 | 3 mos. | 3 yrs | $2.6^{-3}/3.1^{-2}$ | W = L |
| 12 | $1\text{x}10^{-7}$ | 0 | 3 mos. | 3 yrs | $6.9^{-6}/9.9^{-4}$ | W = L |
| 13 | $1.14\text{x}10^{-5}$<br>$1.14\text{x}10^{-6}$<br>$1.14\text{x}10^{-7}$ | 0 | 3 mos. | 1 yr | $7.0^{-3}/1.0^{-1}$ | $6.5^{-6}/2.3^{-}$ |
| 14 | " | 1 mo. | 3 mos. | 1 yr | $7.9^{-4}$ const. | W = L |
| 15 | " | 1 yr. | 3 mos. | 1 yr | $7.0^{-3}/1.1^{-1}$ | $6.5^{-6}/2.3^{-}$ |
| 16 | " | 3 mos. | 3 mos. | 1 yr | $7.0^{-3}/6.9^{-1}$ | $6.5^{-6}/6.4^{-}$ |

NOTES: + 3 values of $\lambda$ shown represent least likely, likely, and most likely event occu

* Number exponents are x10, i.e., $1.8^{-1} = 1.8\text{x}10^{-1}$.

Figures represent beginning of cycle and end of total elapsed time, i.e., $1.8^{-1}/9.$ Values in between are not shown.

Runs: 3,4,5,6,7, & 11 present data on one half of fault tree.

Runs: 9,10,12,13,14,15 & 16 present data on full fault tree.

TABLE 2

MARY OF COMPUTER PROGRAM RESULTS

| TIME VAL ZE) | TOTAL ELAPSED TIME | SYSTEM DATA * Q | W | L | $W_{sum}$ | $F_{sum}$ |
|---|---|---|---|---|---|---|
| | 2 1/2 yrs | $9.9^{-1}/1$ | $2.1^{-3}/.11^{-3}$ | $2.2^{-3}/2.1^{10}/1.6^{10}$ | 6.2/11.09 | 1.0 const. |
| | 2 1/2 yrs | $3.8^{-1}/9.9^{-1}$ | $2.2^{-4}/1.0^{-4}$ | $2.2^{-4}/3.1^{-2}$ | $4/6^{-1}/3.9$ | $4.5^{-1}/1$ |
| | 3 yrs | $3.8^{-1}/5.9^{-1}$ | $2.2^{-4}/1.9^{-4}$ | $2.2^{-4}/4.6^{-4}$ | $4.6^{-1}/8.8^{-1}$ | $4.5^{-1}/9.9^{-1}$ |
| | 3 yrs | $4.6^{-2}/4.3^{-1}$ | $2.2^{-5}/2.1^{-5}$ | $2.2^{-5}/3.5^{-5}$ | $4.8^{-2}/5.5^{-1}$ | $4.8^{-2}/5.2^{-1}$ |
| | 3 yrs | $4.6^{-2}/9.0^{-2}$ | $2.2^{-5}/2.2^{-5}$ | $2.2^{-5}/2.4^{-5}$ | $4.7^{-2}/5.6^{-1}$ | $4.7^{-2}/4.6^{-1}$ |
| | 3 yrs | $9.9^{-1}/1$ | $7.7^{-3}/1.7^{-3}$ | $5.0^{+3}/1.0^{+12}/1.0^{+10}$ | $8.5^{-2}/1.0$ | 1.0 const. |
| | 3 yrs | $9.9^{-1}/1/9.9^{-1}/1$ | $7.7^{-3}/7.2^{-2}$ | $5.0^{+3}/1.0^{+12}$ | 8.5/24.8/42/2.4 | 1.0 const. |
| | 3 yrs | $2.6^{-3}/3.1^{-2}$ | W = L | $1.2\times10^{-6}$ | $2.6^{-3}/3.1^{-2}$ | $2.6^{-3}/3.1^{-2}$ |
| | 3 yrs | $6.9^{-6}/9.9^{-4}$ | W = L | $6.3^{-9}/7.5^{-8}$ | $6.9^{-6}/9.9^{-4}$ | $6.9^{-6}/9.9^{-4}$ |
| | 1 yr | $7.0^{-3}/1.0^{-1}$ | $6.5^{-6}/2.3^{-5}$ | $6.5^{-6}/2.6^{-5}$ | $6.9^{-3}/1.1^{-1}$ | $7.0^{-3}/1.1^{-1}$ |
| | 1 yr | $7.9^{-4}$ const. | W = L | $2.2^{-6}$ const. | $2.4^{-3}/1.6^{-2}$ | $2.4^{-3}/1.6^{-2}$ |
| | 1 yr | $7.0^{-3}/1.1^{-1}$ | $6.5^{-6}/2.3^{-5}$ | $6.5^{-6}/2.6^{-5}$ | $6.9^{-3}/1.1^{-1}$ | $7.0^{-3}/1.1^{-1}$ |
| | 1 yr | $7.0^{-3}/6.9^{-1}$ | $6.5^{-6}/6.4^{-6}$ | $6.5^{-6}/6.4^{-6}$ | $6.9^{-3}/4.9^{-2}$ | $7.0^{-3}/4.8^{-2}$ |

east likely, likely, and most likely event occurence.

$1.8^{-1} = 1.8\times10^{-1}$.

and end of total elapsed time, i.e., $1.8^{-1}/9.9^{-1}$.

on one half of fault tree.

data on full fault tree.



2

of $8.8 \times 10^{-6}$ for the least likely event to occur, $8.8 \times 10^{-5}$ for the likely event, and $8.8 \times 10^{-4}$ for most likely event were selected. Lambdas were then computed from Equation (1) and used in Runs 13, 14, 15 and 16. In addition tau, test and repair rates were varied for intervals of one month, three months, and one year for a total time period of one year. All runs show acceptable values of $W_{sum}$ and $F_{sum}$. The effects of test and repair on a three-month or one-month rate were considered significant. The $W_{sum}$ and $F_{sum}$ values at the <u>end</u> of the operating time interval decrease by an order-of-magnitude, i.e., .11 at one year, without test and repair, to .049 at three-month test and repair, to .016 at one-month test and repair.

An illustration of a typical computer run for both the PREP and KITT programs is shown in Appendix C.

## CONCLUSIONS

1. Fault Tree Analysis can be effectively used on the subject deluge system and other more complicated Manufacturing Technology Programs. It is evident herein that the use of Fault Tree Analysis will provide a safety design review that points out problem areas early in the development cycle. The Fault Tree Analysis approach forces one to look critically at <u>all</u> possible problems which might develop.

2. Fault Tree Analysis of the system, as it appears to be developing, indicatesthat twelve (12) single-point failures exist which could cause Deluge System failure. Nine (9) of these single-point failures can be eliminated ANDing the nozzle lines. This can be accomplished by supplying the nozzle lines on either side of the conveyor separately through a line using its own fill system and controlled explosive valve. That is, each side would be independent except for the main water supply line. This would eliminate 9 of the 12 single-point failures. The remaining three are main-line failures which could be monitored by a line pressure sensing device associated with a system interlock and an audible or visual alarm.

3. Fault Tree Computer Analysis of the proposed base line design shows the need for a periodic testing and repair procedure to assure the reliability of the Deluge System.

4. The type of fire which could result from any explosive considered for use with the subject Deluge System should be more completely characterized. The TNT scale fires demonstrated at SwRI were <u>not</u> of a violent burning nature. If this is typical of the fire to be expected, there is no need for special solid spray nozzles and pressure regulation. This would reduce the number of failure modes considerably, and no doubt reduce system complexity and cost.

5. Each excess flow control valve used in the system represents a failure point. Elimination of these valves coupled with more emphasis on

the explosive protection of nozzles and piping appears necessary to increase the safe and desirable response of the deluge system. Cost savings in eliminating the excess flow valves can be applied to the added cost of nozzle and pipe protection. Piping external to the building and earth protection has been previously suggested. (See Appendix B)

6. Operation of the conveyor system should be interlocked with the Deluge System in such a way that malfunction of the sensing devices and controller will not allow operation of the conveyor.

7. Powering of the protection system could be interlocked with the conveyor operation. There is no need to power the system constantly if it can be concluded that a fire hazard does not exist in the area at times other than when actually conveying explosives.

## RECOMMENDATIONS

1. A Fault Tree Analysis on the final design be developed.

2. Additional investigation be performed on failure probability rates.

3. Each possible failure event in the final system be reviewed to determine test and repair or replacement rate.

4. A test and repair procedure be developed.

5. The feasibility of a permanent monitoring system in conjunction with a mini-computer printout system to provide quick response, periodic test data, be investigated.

6. Monitoring of line pressure, suitable interlocks with the deluge and conveyor systems, and suitable audible or visual alarms be provided in the final design.

## REFERENCES


1. Scope of Work, Deluge System Response, not dated.

2. Southwest Research Institute (SwRI) RFQ response to Scope of Work, not dated.

3. SwRI Monthly Reports, Nos. 1 to 5 inclusive, Contract DAAA21-74-C-0319, 3 May to 13 September 1974.

4. Meeting, Dr. W. McLain, SwRI, at Picatinny Arsenal with Messrs. Rindner and Seals, MTD, and W. J. Coffey, SCB, 22 November 1974.

5. SCB Progress Report, Fault Tree Analysis - Bulk HE Conveyors, Period Covered 10 October to 13 December 1974.

6. Trip Report, dated 29 January 1975 covering trip by W. J. Coffey, SCB, to SwRI, 23 and 24 January 1975.

7. Telephone calls, Messrs. W. Crosby and Ted Larsen, Detector Electronics Corporation, Minneapolis, MN, (612-941-5665) and Mr. W. J. Coffey, SCB, re ultraviolet fire detection systems.

8. Telephone call, Mr. Roy Glodu, Grinnell Corp., Chicago, IL, (312-495-3400) and Mr. W. J. Coffey, SCB, re UV system for control of fire in black powder enclosed conveyor system at Indiana Army Depot, 23 April 1975.

9. Telephone call, Mr. Will Jameson, Lea Engr. Corp., Pittsburg, PA, (412-941-5770) and Mr. W. J. Coffey, SCB, re Bureau of Mines Contract H0122-020 covering control of methane explosives in coal mines using UV heads and dry chemicals under pressure, 23 April 1975.

10. Set Equation Transformation System (SETS)
Worrell, R. B., Sandia Laboratories, SLA-73-0028, to be published.

11. Fault Tree Drawing (FTD) Program User Instructions
Oliver, D. A., Sandia Laboratories, SLA-73-0409, April 1973.

12. PREP and KITT: Computer Programs for the Automatic Evaluation of a Fault Tree
Vesely, W. E., and Marum, R. E., Idaho Nuclear Corporation, IN-1349, TID-4500, August 1970.

13. Aircraft Flight Control Systems Field Safety Experience
Boeing Aerospace Company - AFFDL-TR-72-33, May 72.

14. System Safety Analytical Technology - Fault Hazard Analysis
Boeing Aerospace Company - D2-113072-3, January 72.

APPENDIX A

PROGRESS REPORT

FAULT TREE ANALYSIS-BULK HE CONVEYORS

## APPENDIX A

PROGRESS REPORT

FAULT TREE ANALYSIS - BULK HE CONVEYORS

Period Covered: 10 October to 13 December 1974

The work accomplished and historical sequence of events for the above period is outlined below:

1. A preliminary meeting with Messrs. Rindner and Seals of MTD and Messrs. Reiner and Coffey of ND&ED was held on 10 October 1974. Mr. Reiner reviewed Fault Tree Analysis objectives and procedures. A meeting with the Contractor, SwRI was agreed to at this time tentatively scheduled for early November. We were requested by Mr. Rindner not to expend any effort until this meeting was held.

2. Mr. Rindner advised Mr. Coffey in a telephone conversation of 5 November, that he planned to visit SwRI during week of 11 November. He wished to first review contractors progress before our efforts proceed.

3. A preliminary Fault Tree was developed by Mr. Coffey based on the data available from Scope of Work, SwRI's proposal, and progress reports #1 to #5. Copies of same were furnished Mr. Rindner during a meeting of 22 November with Dr. McLain of SwRI. A copy is attached for reference.

4. Based on discussions with Dr. McLain, in the above meeting, supplemented by information supplied in SwRI Progress Reports #6 and #7, extended development of the preliminary Fault Tree has been accomplished. Three (3) copies of this are attached hereto.

5. As presently developed, it appears that many single point failures to provide no flow or improper flow in the Deluge System can occur. Of particular significance will be the zone size and piping layout supplying the nozzle arrays in each zone. There are many possible alternatives. Various arrangements in this area are being considered for suggestion to MTD based on their effect on the Fault Tree. It also appears that a second parallel method of sensing and triggering the system would be worthy of consideration.

6. Updated system design data and manufacturer's details will be required for further development of the Fault Tree. It is expected that this information will be available shortly. Contact will be made with Dr. McLain after first discussing with Mr. Rindner.

7. Wiring diagrams, manufacturer's specifications, electrical component details and mechanical details on the following items, where applicable, will help to further extend and detail the Fault Tree:

a. Sensing System

b. Explosive Valve

c. Proof Test Valve

d. Excess Flow Valve

e. Pressure Regulating Valve

Respectively Submitted,

William J. Coffey

WILLIAM J. COFFEY 12/16/74

APPENDIX B

TRIP REPORT

APPENDIX B

29 January 1975

**TRIP REPORT**

PLACE VISITED: Southwest Research Institute, San Antonio, TX

DATE OF VISIT: 23-24 January 1975

PURPOSE OF VISIT:

1. Review all design data available which can be used on fault tree analyses being developed by Safety Concepts Branch.

2. Witness testing contemplated during time of visit.

3. Review requirements of project as defined in Scope of Work and SwRI's proposal in order to become familiar with problems yet to be solved, current thinking in their solution, and to appraise MTD of progress to date.

PERSONNEL CONTACTED:

Dr. W.H. McLain, Manager Fire Research Section
Mr. L.A. Eggleston, Senior Research Engineer
Mr. W.R. Herrara, Senior Research Engineer

DISCUSSION:

Dr. McLain review details of testing they were presently trying to accomplish. Namely, characterizing the type of burning a TNT fire would present and the sensing device response at varying distances. He also indicated that, during these tests, the TNT fire response to water extinguishment would be verified. Data on nozzle patterns and density had been taken previously at SwRI and were available. Advance data on tests described herein were hand carried by the writer to be turned over to Mr. Rindner.

SwRI drawings covering design details of a prototype installation assembly were discussed and reviewed by the writer with Dr. McLain. Full size details will be used for final hardware verification and 60# flake TNT detonation testing of prototype design. Scaled models (¼ size) will be used to determine detonation effects on two types of spray nozzle protection housings. Copies of SwRI drawings D-03-3914-01 to 09 were hand carried for delivery to Mr. Rindner also.

A detailed review of the task items covered in the SwRI response to the original Scope of Work appears to indicate that Task I is essentially completed. Dr. McLain feels that their survey work covered the known conveyor lines in operation at the time. There were no operations of a closed hood type brought to his attention. SwRI's response has been directed to the conditions present at the time of their survey.

With respect to Task II most of the work has been completed. The basic approach and design parameters are essentially selected. Dr. McLain concedes that perhaps it would be more advisable to locate piping between spray nozzle protection housings outside the building perimeter below ground and will probably make that a final recommendation. He also stated that the $-40^{\circ}F$ to $140^{\circ}F$ temperature range appears more of a fielded item specification requirement and not necessarily representative of true environments in this application. Dr. McLain expressed a desire to work closely in all areas with the writer and suggested a close liaison in respect to reliability, cost effectiveness, repair and maintenance review and search for additional applications.

Task III involves the construction and testing of small scale and full scale prototype components and/or installations. Some of this testing was witnessed by the writer. Drawings and preparations are in process to complete this task, however, Dr. McLain indicated that he expected to request a three month contract extension.

Daylight, open field testing of a UV sensing device located 5' above and 19', 29' and 60' from the source of a flake TNT fire were conducted on 23 and 24 January 1975. The fire was started by inserting a Nichrome resistance wire in a containing area of 1½" dia, 4" x 4", or 8" x 8" to a leveled depth of approximately ½" flake TNT. When a variac regulated voltage of approximately 40 volts was applied the Nichrome wire glowed red. Within 5 to 10 seconds a small amount of smoke appeared followed by flame ignition which soon covered the entire surface. The deep orange flame was relatively mild and slow burning. Combustion occurred with large amounts of heavy black smoke. Weights of TNT used were 70, 140, 700, 1400, and 5000 grains. The number of sensor counts for each second of flame time were recorded.

Extinguishment of the flame occurs very rapidly in the order of a few seconds. The tests were conducted using a garden hose and nozzle set-up with a flow meter in the line. Splashing of the molten TNT occurred but no re-ignition resulted. Water quantities of the order of .2 gals/sq. ft./min. were adequate. Final design of system will provide .3 gals/sq. ft./min. as a minimum.

With respect to Task IV, technical data package, drawings are being generated, test data accumulated, and component manufacturer's data is available. In addition to SwRI drawings mentioned above, the writer has obtained a large portion of the manufacturer's data for further use in our fault tree analysis. This included parts list, excess flow valves, nozzles, explosive valve, and description of operation and wiring diagrams on the UV detectors. Additional information as required will be obtained directly from the specific manufacturer.

CONCLUSIONS:

Dr. McLain was not certain the Scope of Work actually required more than proof of survival and activation of deluge system after detonation of a 60# box. A joint review of both the Scope of Work and SwRI's proposal clearly indicates a requirement to extinguish a fire as a result of a detonation. SwRI will plan to set a representative fire if no fire arises as a result of initial detonation.

There is data available to indicate that a box of TNT ignited across its top surface will detonate after burning down in part way. The time between ignition and detonation is therefore critical. The deluge system total response time after surviving the initial detonation, sensing a fire, and then extinguishing the fire must be measurably less than the secondary detonation time. If the extinguishment system does not function properly we could have a continuing series reaction up the line.

The detonation may vary from 40 to 60 # TNT equivalency. A 40 # equivalency will result in a greater number of burning brans, which together with parts of the burning box, travel a short distance. A pressure wave will occur and adjoining boxes may be moved down the conveyor or off to the sides. Characterization of the detonation and expected side effects, if not already known, should be determined.

RECOMMENDATIONS:

A clear definition of all tests to be conducted to completion of the contract should be made. Outlining what each Test is expected to accomplish and how each parameter will be determined should be mutually agreed upon between SwRI and PA.

Some understanding on the photo coverage expected by both parties should be outlined.

A total system layout should be generated for lines up to 500 feet long. Zone size should be specified. Recommended feeding of the system, each zone and each nozzle in the system should be determined.

An understanding regarding the items expected in the Technical Data Package should be reached.

Any data available through MTD on the characterization of TNT detonation, pressure wave response, bran burning velocities and behavior, expected movement of adjoining boxes, and detonation times should be made available to SwRI.

William J. Coffey 1/30/78

WILLIAM J. COFFEY
Safety Concepts Branch, CMED, MIED

Cy Furn:
Ch, MTD

APPENDIX C

TYPICAL COMPUTER RUN

```
*****************************************************************************************************
*TREBIL FAULT TREE BUILDING PROGRAM
*****************************************************************************************************

 DELUGE SYSTEM A-1
NUMBER OF GATES,NG-------------------------  125
COMBO STARTING VALUE,MIN-------------------    2
COMBO ENDING VALUE,MAX---------------------    2
CUT SET - PATH SET SWITCH,IDEX1------------   -0
PRINT - PUNCH SWITCH,IDEX2-----------------    1
MONTE CARLO STARTER,MCS--------------------    0
NO. OF RANDOM NUMBERS TO REJECT,NREJEC-----    0
NO. OF MONTE CARLO TRIALS,NTR--------------    0
MIXING PARAMETER SWITCH,IREN---------------    0
MONTE CARLO MIXING PARAMETER,TAA-----------.0
```

*TREBIL FAULT TREE BUILDING PROGRAM

DELUGE SYSTEM A-1

| NAME | TYPE | | | INPUTS---- | |
|---|---|---|---|---|---|
| FAILS | AND | 2 | 0 | OR15 | OR15 |
| AND01 | AND | 1 | 1 | OR06 | E10 |
| AND02 | AND | 2 | 0 | OR11 | OR11X |
| AND03 | AND | 2 | 0 | OR11Y | OR11Z |
| AND04 | AND | 2 | 0 | OR12 | OR13 |
| OR01 | OR | 1 | 1 | OR1112 | E13 |
| OR02 | OR | 1 | 1 | OR01 | E07 |
| OR03 | OR | 0 | 2 | E08 | E09 |
| OR04 | OR | 2 | 0 | OR1617 | OR1819 |
| OR05 | OR | 2 | 0 | OR2021 | OR2223 |
| OR06 | OR | 2 | 0 | OR04 | OR05 |
| OR07 | OR | 2 | 0 | OR0203 | AND01 |
| OR12 | OR | 1 | 1 | AND02 | E14 |
| OR13 | OR | 1 | 1 | AND03 | E15 |
| OR14 | OR | 1 | 1 | AND04 | E06 |
| OR15 | OR | 2 | 0 | OR010702 | OR041405 |
| OR0107 | OR | 1 | 1 | OR07 | E01 |
| ORE0203 | OR | 0 | 2 | E02 | E03 |
| OR0414 | OR | 1 | 1 | OR14 | E04 |
| OR010702 | OR | 2 | 0 | OR0107 | ORE0203 |
| OR041405 | OR | 1 | 1 | OR0414 | E05 |
| OR1112 | OR | 0 | 2 | E11 | E12 |
| OR1617 | OR | 0 | 2 | E16 | E17 |
| OR1819 | OR | 0 | 2 | E18 | E19 |
| OR2021 | OR | 0 | 2 | E20 | E21 |
| OR2223 | OR | 0 | 2 | E22 | E23 |
| OR0203 | OR | 2 | 0 | OR02 | OR03 |
| OR08 | OR | 0 | 2 | E25 | E26 |
| OR08X | OR | 0 | 2 | E25X | E26X |
| OR08Y | OR | 0 | 2 | E25Y | E26Y |
| OR08Z | OR | 0 | 2 | E25Z | E26Z |
| OR09 | OR | 1 | 1 | OR3031 | U02 |
| OR09X | OR | 1 | 1 | OR3031X | U02X |
| OR09Y | OR | 1 | 1 | OR3031Y | U02Y |
| OR09Z | OR | 1 | 1 | OR3031Z | U02Z |
| OR10 | OR | 2 | 0 | OR2728 | OR290109 |
| OR10X | OR | 2 | 0 | OR2728X | OR29010X |
| OR10Y | OR | 2 | 0 | OR2728Y | OR29010Y |
| OR10Z | OR | 2 | 0 | OR2728Z | OR29010Z |
| OR11 | OR | 2 | 0 | OR0824 | OR10 |
| OR11X | OR | 2 | 0 | OR0824X | OR10X |
| OR11Y | OR | 2 | 0 | OR0824Y | OR10Y |
| OR11Z | OR | 2 | 0 | OR0824Z | OR10Z |
| OR2728 | OR | 0 | 2 | E27 | E28 |
| OR2728X | OR | 0 | 2 | E27X | E28X |
| OR2728Y | OR | 0 | 2 | E27Y | E28Y |
| OR2728Z | OR | 0 | 2 | E27Z | E28Z |
| OR2901 | OR | 0 | 2 | E29 | U01 |
| OR2901X | OR | 0 | 2 | E29X | U01X |
| OR2901Y | OR | 0 | 2 | E29Y | U01Y |
| OR2901Z | OR | 0 | 2 | E29Z | U01Z |
| OR290109 | OR | 2 | 0 | OR2901 | OR09 |
| OR29010X | OR | 2 | 0 | OR2901X | OR09X |
| OR29010Y | OR | 2 | 0 | OR2901Y | OR09Y |
| OR29010Z | OR | 2 | 0 | OR2901Z | OR09Z |
| OR3031 | OR | 0 | 2 | E30 | E31 |

| | | | | | |
|---|---|---|---|---|---|
| OR3031X | OR | 0 | 2 | E30X | E31X |
| OR3031Y | OR | 0 | 2 | E30Y | E31Y |
| OR3031Z | OR | 0 | 2 | E30Z | E31Z |
| OR0824 | OR | 1 | 1 | OR08 | E24 |
| OR0824X | OR | 1 | 1 | OR08X | E24X |
| OR0824Y | OR | 1 | 1 | OR08Y | E24Y |
| OR0824Z | OR | 1 | 1 | OR08Z | E24Z |
| UND01 | AND | 1 | 1 | UR06 | C10 |
| UND02 | AND | 2 | 0 | UR11 | UR11X |
| UND03 | AND | 2 | 0 | UR11Y | UR11Z |
| UND04 | AND | 2 | 0 | UR12 | UR13 |
| UR01 | OR | 1 | 1 | UR1112 | C13 |
| UR02 | OR | 1 | 1 | UR01 | C07 |
| UR03 | OR | 0 | 2 | C08 | C09 |
| UR04 | OR | 2 | 0 | UR1617 | UR1819 |
| UR05 | OR | 2 | 0 | UR2021 | UR2223 |
| UR06 | OR | 2 | 0 | UR04 | UR05 |
| UR07 | OR | 2 | 0 | UR0203 | UND01 |
| UR12 | OR | 1 | 1 | UND02 | C14 |
| UR13 | OR | 1 | 1 | UND03 | C15 |
| UR14 | OR | 1 | 1 | UND04 | C06 |
| UR15 | OR | 2 | 0 | UR010702 | UR041405 |
| UR0107 | OR | 1 | 1 | UR07 | C01 |
| URE0203 | OR | 0 | 2 | C02 | C03 |
| UR0414 | OR | 1 | 1 | UR14 | C04 |
| UR010702 | OR | 2 | 0 | UR0107 | URE0203 |
| UR041405 | OR | 1 | 1 | UR0414 | C05 |
| UR1112 | OR | 0 | 2 | C11 | C12 |
| UR1617 | OR | 0 | 2 | C16 | C17 |
| UR1819 | OR | 0 | 2 | C18 | C19 |
| UR2021 | OR | 0 | 2 | C20 | C21 |
| UR2223 | OR | 0 | 2 | C22 | C23 |
| UR0203 | OR | 2 | 0 | UR02 | UR03 |
| UR08 | OR | 0 | 2 | C25 | C26 |
| UR08X | OR | 0 | 2 | C25X | C26X |
| UR08Y | OR | 0 | 2 | C25Y | C26Y |
| UR08Z | OR | 0 | 2 | C25Z | C26Z |
| UR09 | OR | 1 | 1 | UR3031 | V02 |
| UR09X | OR | 1 | 1 | UR3031X | V02X |
| UR09Y | OR | 1 | 1 | UR3031Y | V02Y |
| UR09Z | OR | 1 | 1 | UR3031Z | V02Z |
| UR10 | OR | 2 | 0 | UR2728 | UR290109 |
| UR10X | OR | 2 | 0 | UR2728X | UR29010X |
| UR10Y | OR | 2 | 0 | UR2728Y | UR29010Y |
| UR10Z | OR | 2 | 0 | UR2728Z | UR29010Z |
| UR11 | OR | 2 | 0 | UR0824 | UR10 |
| UR11X | OR | 2 | 0 | UR0824X | UR10X |
| UR11Y | OR | 2 | 0 | UR0824Y | UR10Y |
| UR11Z | OR | 2 | 0 | UR0824Z | UR10Z |
| UR2724 | OR | 0 | 2 | C27 | C28 |
| UR2728X | OR | 0 | 2 | C27X | C28X |
| UR2728Y | OR | 0 | 2 | C27Y | C28Y |
| UR2728Z | OR | 0 | 2 | C27Z | C28Z |
| UR2901 | OR | 0 | 2 | C29 | V01 |
| UR2901X | OR | 0 | 2 | C29X | V01X |
| UR2901Y | OR | 0 | 2 | C29Y | V01Y |
| UR2901Z | OR | 0 | 2 | C29Z | V01Z |
| UR290109 | OR | 2 | 0 | UR2901 | UR09 |
| UR29010X | OR | 2 | 0 | UR2901X | UR09X |
| UR29010Y | OR | 2 | 0 | UR2901Y | UR09Y |
| UR29010Z | OR | 2 | 0 | UR2901Z | UR09Z |
| UR3031 | OR | 0 | 2 | C30 | C31 |
| UR3031X | OR | 0 | 2 | C30X | C31X |
| UR3031Y | OR | 0 | 2 | C30Y | C31Y |
| UR3031Z | OR | 0 | 2 | C30Z | C31Z |
| UR0824 | OR | 1 | 1 | UR08 | C24 |

```
UR0824X  OR    1 1 UR08X     C24X
UR0824Y  OR    1 1 UR08Y     C24Y
UR0824Z  OR    1 1 UR08Z     C24Z
END             -0-0
```

```
******************************************************************************************
*TREBIL FAULT TREE BUILDING PROGRAM
******************************************************************************************

 DELUGE SYSTEM A-1

        THIS IS THE SUBROUTINE GENERATED BY TREBIL
      SUBROUTINE TREE
      LOGICAL TOP,A( 500),X( 500)
      COMMON/TREES/A,X,TOP
      A(   1) = X(   1).OR.X(   2)
      A(   2) = X(   3).OR.X(   4)
      A(   3) = X(   5).OR.X(   6)
      A(   4) = X(   7).OR.X(   8)
      A(   5) = X(   9).OR.X(  10)
      A(   6) = X(  11).OR.X(  12)
      A(   7) = X(  13).OR.X(  14)
      A(   8) = X(  15).OR.X(  16)
      A(   9) = X(  17).OR.X(  18)
      A(  10) = X(  19).OR.X(  20)
      A(  11) = X(  21).OR.X(  22)
      A(  12) = X(  23).OR.X(  24)
      A(  13) = X(  25).OR.X(  26)
      A(  14) = X(  27).OR.X(  28)
      A(  15) = X(  29).OR.X(  30)
      A(  16) = X(  31).OR.X(  32)
      A(  17) = X(  33).OR.X(  34)
      A(  18) = X(  35).OR.X(  36)
      A(  19) = X(  37).OR.X(  38)
      A(  20) = X(  39).OR.X(  40)
      A(  21) = X(  41).OR.X(  42)
      A(  22) = X(  43).OR.X(  44)
      A(  23) = X(  45).OR.X(  46)
      A(  24) = X(  47).OR.X(  48)
      A(  25) = X(  49).OR.X(  50)
      A(  26) = X(  51).OR.X(  52)
      A(  27) = X(  53).OR.X(  54)
      A(  28) = X(  55).OR.X(  56)
      A(  29) = X(  57).OR.X(  58)
      A(  30) = X(  59).OR.X(  60)
      A(  31) = X(  61).OR.X(  62)
      A(  32) = X(  63).OR.X(  64)
      A(  33) = X(  65).OR.X(  65)
      A(  34) = X(  67).OR.X(  68)
      A(  35) = X(  69).OR.X(  70)
      A(  36) = X(  71).OR.X(  72)
      A(  37) = X(  73).OR.X(  74)
      A(  38) = X(  75).OR.X(  76)
      A(  39) = X(  77).OR.X(  78)
      A(  40) = X(  79).OR.X(  80)
      A(  41) = X(  81).OR.X(  82)
      A(  42) = X(  83).OR.X(  84)
      A(  43) = X(  85).OR.X(  86)
      A(  44) = X(  87).OR.X(  88)
      A(  45) = X(  89).OR.X(  90)
      A(  46) = X(  91).OR.X(  92)
      A(  47) = A(  13)
     *           .OR.X(  93)
      A(  48) = A(  14)
     *           .OR.X(  94)
      A(  49) = A(  15)
     *           .OR.X(  95)
      A(  50) = A(  16)
```

```
     *          .OR.X(  96)
      A(  51) = A(   1)
     *          .OR.X(  97)
      A(  52) = A(   2)
     *          .OR.X(  98)
      A(  53) = A(   3)
     *          .OR.X(  99)
      A(  54) = A(   4)
     *          .OR.X( 100)
      A(  55) = A(  18).OR.A(  17)
      A(  56) = A(  20).OR.A(  19)
      A(  57) = A(  21)
     *          .OR.X( 101)
      A(  58) = A(  36)
     *          .OR.X( 102)
      A(  59) = A(  37)
     *          .OR.X( 103)
      A(  60) = A(  38)
     *          .OR.X( 104)
      A(  61) = A(  39)
     *          .OR.X( 105)
      A(  62) = A(  24)
     *          .OR.X( 106)
      A(  63) = A(  25)
     *          .OR.X( 107)
      A(  64) = A(  26)
     *          .OR.X( 108)
      A(  65) = A(  27)
     *          .OR.X( 109)
      A(  66) = A(  41).OR.A(  40)
      A(  67) = A(  43).OR.A(  42)
      A(  68) = A(  44)
     *          .OR.X( 110)
      A(  69) = A(   5).OR.A(  51)
      A(  70) = A(   6).OR.A(  52)
      A(  71) = A(   7).OR.A(  53)
      A(  72) = A(   8).OR.A(  54)
      A(  73) = A(   9).OR.A(  69)
      A(  74) = A(  10).OR.A(  70)
      A(  75) = A(  11).OR.A(  71)
      A(  76) = A(  12).OR.A(  72)
      A(  77) = A(  56).OR.A(  55)
      A(  78) = A(  57)
     *          .OR.X( 111)
      A(  79) = A(  77)
     *          .AND.X( 112)
      A(  80) = A(  28).OR.A(  62)
      A(  81) = A(  29).OR.A(  63)
      A(  82) = A(  30).OR.A(  64)
      A(  83) = A(  31).OR.A(  65)
      A(  84) = A(  32).OR.A(  80)
      A(  85) = A(  33).OR.A(  81)
      A(  86) = A(  34).OR.A(  82)
      A(  87) = A(  35).OR.A(  83)
      A(  88) = A(  67).OR.A(  66)
      A(  89) = A(  68)
     *          .OR.X( 113)
      A(  90) = A(  88)
     *          .AND.X( 114)
      A(  91) = A(  47).OR.A(  73)
      A(  92) = A(  48).OR.A(  74)
      A(  93) = A(  49).OR.A(  75)
      A(  94) = A(  50).OR.A(  76)
      A(  95) = A(  78).OR.A(  23)
      A(  96) = A(  95).OR.A(  79)
      A(  97) = A(  92).AND.A(  91)
```

```
      A(  98) = A(  94).AND.A(  33)
      A(  99) = A(  58).OR.A(  84)
      A( 100) = A(  59).OR.A(  85)
      A( 101) = A(  60).OR.A(  86)
      A( 102) = A(  61).OR.A(  87)
      A( 103) = A(  89).OR.A(  46)
      A( 104) = A( 103).OR.A(  90)
      A( 105) = A( 100).AND.A(  99)
      A( 106) = A( 102).AND.A( 101)
      A( 107) = A(  96)
     *          .OR.X( 115)
      A( 108) = A(  97)
     *          .OR.X( 116)
      A( 109) = A(  98)
     *          .OR.X( 117)
      A( 110) = A( 109).AND.A( 108)
      A( 111) = A( 104)
     *          .OR.X( 118)
      A( 112) = A( 105)
     *          .OR.X( 119)
      A( 113) = A( 106)
     *          .OR.X( 120)
      A( 114) = A( 113).AND.A( 112)
      A( 115) = A( 107).OR.A(  22)
      A( 116) = A( 110)
     *          .OR.X( 121)
      A( 117) = A( 111).OR.A(  45)
      A( 118) = A( 114)
     *          .OR.X( 122)
      A( 119) = A( 116)
     *          .OR.X( 123)
      A( 120) = A( 118)
     *          .OR.X( 124)
      A( 121) = A( 119)
     *          .OR.X( 125)
      A( 122) = A( 115).OR.A( 121)
      A( 123) = A( 120)
     *          .OR.X( 126)
      A( 124) = A( 117).OR.A( 123)
      A( 125) = A( 124).AND.A( 122)
       TOP = A( 125)
      RETURN
      END

 THERE WERE   126 COMPONENTS INDEXED IN THIS TREE
```

*TREBIL FAULT TREE BUILDING PROGRAM

DELUGE SYSTEM A-1

COMPONENT INDICES, NAMES, AND FAILURE RATES (PER HOUR) -

| TREE INDEX | COMPONENT NAME | LAMBDA(FAILURE INTENSITY/HR.) | TAU |
|---|---|---|---|
| 1 | C30Z | 4.63000D-04 | -0. |
| 2 | C31Z | 1.38900D-04 | -0. |
| 3 | C30Y | 4.63000D-04 | -0. |
| 4 | C31Y | 1.38900D-04 | -0. |
| 5 | C30X | 4.63000D-04 | -0. |
| 6 | C31X | 1.38900D-04 | -0. |
| 7 | C30 | 4.63000D-04 | -0. |
| 8 | C31 | 1.38900D-04 | -0. |
| 9 | C29Z | 4.63000D-04 | -0. |
| 10 | V01Z | 1.38900D-04 | -0. |
| 11 | C29Y | 4.63000D-04 | -0. |
| 12 | V01Y | 1.38900D-04 | -0. |
| 13 | C29X | 4.63000D-04 | -0. |
| 14 | V01X | 1.38900D-04 | -0. |
| 15 | C29 | 4.63000D-04 | -0. |
| 16 | V01 | 1.38900D-04 | -0. |
| 17 | C27Z | 4.63000D-04 | -0. |
| 18 | C28Z | 4.63000D-04 | -0. |
| 19 | C27Y | 4.63000D-04 | -0. |
| 20 | C28Y | 4.63000D-04 | -0. |
| 21 | C27X | 4.63000D-04 | -0. |
| 22 | C28X | 4.63000D-04 | -0. |
| 23 | C27 | 4.63000D-04 | -0. |
| 24 | C28 | 4.63000D-04 | -0. |
| 25 | C25Z | 4.63000D-04 | -0. |
| 26 | C26Z | 4.63000D-04 | -0. |
| 27 | C25Y | 4.63000D-04 | -0. |
| 28 | C26Y | 4.63000D-04 | -0. |
| 29 | C25X | 4.63000D-04 | -0. |
| 30 | C26X | 4.63000D-04 | -0. |
| 31 | C25 | 4.63000D-04 | -0. |
| 32 | C26 | 4.63000D-04 | -0. |
| 33 | C22 | 1.38900D-04 | -0. |
| 34 | C23 | 1.38900D-04 | -0. |
| 35 | C20 | 1.38900D-04 | -0. |
| 36 | C21 | 1.38900D-04 | -0. |
| 37 | C18 | 1.38900D-04 | -0. |
| 38 | C19 | 4.63000D-04 | -0. |
| 39 | C16 | 1.38900D-04 | -0. |
| 40 | C17 | 1.38900D-04 | -0. |
| 41 | C11 | 4.63000D-05 | -0. |
| 42 | C12 | 1.38900D-04 | -0. |
| 43 | C02 | 1.38900D-04 | -0. |
| 44 | C03 | 4.63000D-04 | -0. |
| 45 | C08 | 4.63000D-05 | -0. |
| 46 | C09 | 4.63000D-05 | -0. |
| 47 | E30Z | 4.63000D-04 | -0. |
| 48 | E31Z | 1.38300D-04 | -0. |
| 49 | E30Y | 4.63000D-04 | -0. |
| 50 | E31Y | 1.38900D-04 | -0. |
| 51 | E30X | 4.63000D-04 | -0. |
| 52 | E31X | 1.38900D-04 | -0. |
| 53 | E30 | 4.63000D-04 | -0. |

| | | | |
|---|---|---|---|
| 54 | E31 | 1.389000D-04 | -0. |
| 55 | E29Z | 4.630000D-04 | -0. |
| 56 | U01Z | 1.389000D-04 | -0. |
| 57 | E29Y | 4.630000D-04 | -0. |
| 58 | U01Y | 1.389000D-04 | -0. |
| 59 | E29X | 4.630000D-04 | -0. |
| 60 | U01X | 1.389000D-04 | -0. |
| 61 | E29 | 4.630000D-04 | -0. |
| 62 | U01 | 1.389000D-04 | -0. |
| 63 | E27Z | 4.630000D-04 | -0. |
| 64 | E28Z | 4.630000D-04 | -0. |
| 65 | E27Y | 4.630000D-04 | -0. |
| 66 | E28Y | 4.630000D-04 | -0. |
| 67 | E27X | 4.630000D-04 | -0. |
| 68 | E28X | 4.630000D-04 | -0. |
| 69 | E27 | 4.630000D-04 | -0. |
| 70 | E28 | 4.630000D-04 | -0. |
| 71 | E25Z | 4.630000D-04 | -0. |
| 72 | E26Z | 4.630000D-04 | -0. |
| 73 | E25Y | 4.630000D-04 | -0. |
| 74 | E26Y | 4.630000D-04 | -0. |
| 75 | E25X | 4.630000D-04 | -0. |
| 76 | E26X | 4.630000D-04 | -0. |
| 77 | E25 | 4.630000D-04 | -0. |
| 78 | E26 | 4.630000D-04 | -0. |
| 79 | E22 | 1.389000D-04 | -0. |
| 80 | E23 | 1.389000D-04 | -0. |
| 81 | E20 | 1.389000D-04 | -0. |
| 82 | E21 | 1.389000D-04 | -0. |
| 83 | E18 | 1.389000D-04 | -0. |
| 84 | E19 | 4.630000D-04 | -0. |
| 85 | E16 | 1.389000D-04 | -0. |
| 86 | E17 | 1.389000D-04 | -0. |
| 87 | E11 | 4.630000D-05 | -0. |
| 88 | E12 | 1.389000D-04 | -0. |
| 89 | E02 | 1.389000D-04 | -0. |
| 90 | E03 | 4.630000D-04 | -0. |
| 91 | E08 | 4.630000D-05 | -0. |
| 92 | E09 | 4.630000D-05 | -0. |
| 93 | C24Z | 4.630000D-04 | -0. |
| 94 | C24Y | 4.630000D-04 | -0. |
| 95 | C24X | 4.630000D-04 | -0. |
| 96 | C24 | 4.630000D-04 | -0. |
| 97 | V02Z | 1.389000D-04 | -0. |
| 98 | V02Y | 1.389000D-04 | -0. |
| 99 | V02X | 1.389000D-04 | -0. |
| 100 | V02 | 1.389000D-04 | -0. |
| 101 | C13 | 1.389000D-04 | -0. |
| 102 | E24Z | 4.630000D-04 | -0. |
| 103 | E24Y | 4.630000D-04 | -0. |
| 104 | E24X | 4.630000D-04 | -0. |
| 105 | E24 | 4.630000D-04 | -0. |
| 106 | U02Z | 1.389000D-04 | -0. |
| 107 | U02Y | 1.389000D-04 | -0. |
| 108 | U02X | 1.389000D-04 | -0. |
| 109 | U02 | 1.389000D-04 | -0. |
| 110 | E13 | 1.389000D-04 | -0. |
| 111 | C07 | 4.630000D-04 | -0. |
| 112 | C10 | 4.630000D-04 | -0. |
| 113 | E07 | 4.630000D-04 | -0. |
| 114 | E10 | 4.630000D-04 | -0. |
| 115 | C01 | 4.630000D-04 | -0. |
| 116 | C15 | 4.630000D-04 | -0. |
| 117 | C14 | 4.630000D-04 | -0. |
| 118 | E01 | 4.630000D-04 | -0. |
| 119 | E15 | 4.630000D-04 | -0. |

| | | | |
|---|---|---|---|
| 120 | E14 | 4.63000D-04 | -0. |
| 121 | C06 | 1.38900D-04 | -0. |
| 122 | E06 | 1.38900D-04 | -0. |
| 123 | C04 | 4.63000D-05 | -0. |
| 124 | E04 | 4.63000D-05 | -0. |
| 125 | C05 | 4.63000D-05 | -0. |
| 126 | E05 | 4.63000D-05 | -0. |

**************************************************************************************************************

TREBIL FAULT TREE BUILDING PROGRAM*

**************************************************************************************************************

DELUGE SYSTEM A-1

| TREE INDEX | COMPONENT NAME | NUMBER OF GATES INPUT | GATES INPUT BY THIS COMPONENT |
|---|---|---|---|
| 1 | C30Z | 1 | UR3031Z |
| 2 | C31Z | 1 | UR3031Z |
| 3 | C30Y | 1 | UR3031Y |
| 4 | C31Y | 1 | UR3031Y |
| 5 | C30X | 1 | UR3031X |
| 6 | C31X | 1 | UR3031X |
| 7 | C30 | 1 | UR3031 |
| 8 | C31 | 1 | UR3031 |
| 9 | C29Z | 1 | UR2901Z |
| 10 | V01Z | 1 | UR2901Z |
| 11 | C29Y | 1 | UR2901Y |
| 12 | V01Y | 1 | UR2901Y |
| 13 | C29X | 1 | UR2901X |
| 14 | V01X | 1 | UR2901X |
| 15 | C29 | 1 | UR2901 |
| 16 | V01 | 1 | UR2901 |
| 17 | C27Z | 1 | UR2728Z |
| 18 | C28Z | 1 | UR2728Z |
| 19 | C27Y | 1 | UR2728Y |
| 20 | C28Y | 1 | UR2728Y |
| 21 | C27X | 1 | UR2728X |
| 22 | C28X | 1 | UR2728X |
| 23 | C27 | 1 | UR2728 |
| 24 | C28 | 1 | UR2728 |
| 25 | C25Z | 1 | UR08Z |
| 26 | C26Z | 1 | UR08Z |
| 27 | C25Y | 1 | UR08Y |
| 28 | C26Y | 1 | UR08Y |
| 29 | C25X | 1 | UR08X |
| 30 | C26X | 1 | UR08X |
| 31 | C25 | 1 | UR08 |
| 32 | C26 | 1 | UR08 |
| 33 | C22 | 1 | UR2223 |
| 34 | C23 | 1 | UR2223 |
| 35 | C20 | 1 | UR2021 |
| 36 | C21 | 1 | UR2021 |
| 37 | C18 | 1 | UR1819 |
| 38 | C19 | 1 | UR1819 |
| 39 | C16 | 1 | UR1617 |
| 40 | C17 | 1 | UR1617 |
| 41 | C11 | 1 | UR1112 |
| 42 | C12 | 1 | UR1112 |
| 43 | C02 | 1 | URE0203 |
| 44 | C03 | 1 | URE0203 |
| 45 | C08 | 1 | UR03 |
| 46 | C09 | 1 | UR03 |
| 47 | E30Z | 1 | OR3031Z |
| 48 | E31Z | 1 | OR3031Z |
| 49 | E30Y | 1 | OR3031Y |
| 50 | E31Y | 1 | OR3031Y |
| 51 | E30X | 1 | OR3031X |
| 52 | E31X | 1 | OR3031X |
| 53 | E30 | 1 | OR3031 |
| 54 | E31 | 1 | OR3031 |
| 55 | E29Z | 1 | OR2901Z |
| 56 | U01Z | 1 | OR2901Z |
| 57 | E29Y | 1 | OR2901Y |
| 58 | U01Y | 1 | OR2901Y |
| 59 | E29X | 1 | OR2901X |

| | | | |
|---|---|---|---|
| [illegible] | [illegible] | 1 | [illegible] |
| 61 | E29 | 1 | OR29[illegible]1 |
| 62 | U01 | 1 | OR2901 |
| 63 | E27Z | 1 | OR2728Z |
| 64 | E28Z | 1 | OR2728Z |
| 65 | E27Y | 1 | OR2728Y |
| 66 | E28Y | 1 | OR2728Y |
| 67 | E27X | 1 | OR2728X |
| 68 | E28X | 1 | OR2728X |
| 69 | E27 | 1 | OR2728 |
| 70 | E28 | 1 | OR2728 |
| 71 | E25Z | 1 | OR08Z |
| 72 | E26Z | 1 | OR08Z |
| 73 | E25Y | 1 | OR08Y |
| 74 | E26Y | 1 | OR08Y |
| 75 | E25X | 1 | OR08X |
| 76 | E26X | 1 | OR08X |
| 77 | E25 | 1 | OR08 |
| 78 | E26 | 1 | OR08 |
| 79 | E22 | 1 | OR2223 |
| 80 | E23 | 1 | OR2223 |
| 81 | E20 | 1 | OR2021 |
| 82 | E21 | 1 | OR2021 |
| 83 | E18 | 1 | OR1819 |
| 84 | E19 | 1 | OR1819 |
| 85 | E16 | 1 | OR1617 |
| 86 | E17 | 1 | OR1617 |
| 87 | E11 | 1 | OR1112 |
| 88 | E12 | 1 | OR1112 |
| 89 | E02 | 1 | ORE0203 |
| 90 | E03 | 1 | ORE0203 |
| 91 | E08 | 1 | OR03 |
| 92 | E09 | 1 | OR03 |
| 93 | C24Z | 1 | UR0824Z |
| 94 | C24Y | 1 | UR0824Y |
| 95 | C24X | 1 | UR0824X |
| 96 | C24 | 1 | UR0824 |
| 97 | V02Z | 1 | UR09Z |
| 98 | V02Y | 1 | UR09Y |
| 99 | V02X | 1 | UR09X |
| 100 | V02 | 1 | UR09 |
| 101 | C13 | 1 | UR01 |
| 102 | E24Z | 1 | OR0824Z |
| 103 | E24Y | 1 | OR0824Y |
| 104 | E24X | 1 | OR0824X |
| 105 | E24 | 1 | OR0824 |
| 106 | U02Z | 1 | OR09Z |
| 107 | U02Y | 1 | OR09Y |
| 108 | U02X | 1 | OR09X |
| 109 | U02 | 1 | OR09 |
| 110 | E13 | 1 | OR01 |
| 111 | C07 | 1 | UR02 |
| 112 | C10 | 1 | UND01 |
| 113 | E07 | 1 | OR02 |
| 114 | E10 | 1 | AND01 |
| 115 | C01 | 1 | UR0107 |
| 116 | C15 | 1 | UR13 |
| 117 | C14 | 1 | UR12 |
| 118 | E01 | 1 | OR0107 |
| 119 | E15 | 1 | OR13 |
| 120 | E14 | 1 | OR12 |
| 121 | C06 | 1 | UR14 |
| 122 | E06 | 1 | OR14 |
| 123 | C04 | 1 | UR0414 |
| 124 | E04 | 1 | OR0414 |
| 125 | C05 | 1 | UR041405 |

```
***************************************************************************************
MINIMAL CUT SETS FOUND BY COMBO FOR  DELUGE SYSTEM A-1
***************************************************************************************

MINIMAL CUT SET NO.      1
   E11          C11
CORRESPONDING GATE FAILURES-
     21      44      57      68      78      89      95      96     103     104     107     111
    115     117     122     124     125

MINIMAL CUT SET NO.      2
   E11          C12
CORRESPONDING GATE FAILURES-
     21      44      57      68      78      89      95      96     103     104     107     111
    115     117     122     124     125

MINIMAL CUT SET NO.      3
   E11          C02
CORRESPONDING GATE FAILURES-
     22      44      68      89     103     104     111     115     117     122     124     125

MINIMAL CUT SET NO.      4
   E11          C03
CORRESPONDING GATE FAILURES-
     22      44      68      89     103     104     111     115     117     122     124     125

MINIMAL CUT SET NO.      5
   E11          C08
CORRESPONDING GATE FAILURES-
     23      44      68      89      95      96     103     104     107     111     115     117
    122     124     125

MINIMAL CUT SET NO.      6
   E11          C09
CORRESPONDING GATE FAILURES-
     23      44      68      89      95      96     103     104     107     111     115     117
    122     124     125

MINIMAL CUT SET NO.      7
   E12          C11
CORRESPONDING GATE FAILURES-
     21      44      57      68      78      89      95      96     103     104     107     111
    115     117     122     124     125

MINIMAL CUT SET NO.      8
   E12          C12
CORRESPONDING GATE FAILURES-
     21      44      57      68      78      89      95      96     103     104     107     111
    115     117     122     124     125

MINIMAL CUT SET NO.      9
   E12          C02
CORRESPONDING GATE FAILURES-
     22      44      68      89     103     104     111     115     117     122     124     125
```

```
MINIMAL CUT SET NO.     10
   E12            C03
CORRESPONDING GATE FAILURES-
     22     44     68     89     103    104    111    115    117    122    124    125

MINIMAL CUT SET NO.     11
   E12            C08
CORRESPONDING GATE FAILURES-
     23     44     68     89     95     96     103    104    107    111    115    117
    122    124    125

MINIMAL CUT SET NO.     12
   E12            C09
CORRESPONDING GATE FAILURES-
     23     44     68     89     95     96     103    104    107    111    115    117
    122    124    125

MINIMAL CUT SET NO.     13
   E02            C11
CORRESPONDING GATE FAILURES-
     21     45     57     78     95     96     107    115    117    122    124    125

MINIMAL CUT SET NO.     14
   E02            C12
CORRESPONDING GATE FAILURES-
     21     45     57     78     95     96     107    115    117    122    124    125

MINIMAL CUT SET NO.     15
   E02            C02
CORRESPONDING GATE FAILURES-
     22     45     115    117    122    124    125

MINIMAL CUT SET NO.     16
   E02            C03
CORRESPONDING GATE FAILURES-
     22     45     115    117    122    124    125

MINIMAL CUT SET NO.     17
   E02            C08
CORRESPONDING GATE FAILURES-
     23     45     95     96     107    115    117    122    124    125

MINIMAL CUT SET NO.     18
   E02            C09
CORRESPONDING GATE FAILURES-
     23     45     95     96     107    115    117    122    124    125

MINIMAL CUT SET NO.     19
   E03            C11
CORRESPONDING GATE FAILURES-
     21     45     57     78     95     96     107    115    117    122    124    125

MINIMAL CUT SET NO.     20
   E03            C12
CORRESPONDING GATE FAILURES-
```

```
FRED,CM120000,T1=,1016.
COMMENT.(880-331,910ASE),MULLER
REWIND,INPUT.
COPYSBF.
REWIND,INPUT.
COPYBR,INPUT,S.
COPYBR,INPUT,TAPE5.
ATTACH,TAPE7,PREPOUT,ID=MULLERFA.
REWIND,TAPE5,TAPE7.
ATTACH,A,LILKIT,ID=MULLERFA.
FTN,I=A,L=0.
LGO.
 DELUGE SYSTEM A-1
          1
          1
          5         1 2160.
          1
```

* PROBLEM TITLE FOR THIS ANALYSIS BY KITT-1. DELUGE SYSTEM A-1

NO. OF PARAMETER RUNS (NPROB) = 1

NO. OF COMPONENTS AND INHIBIT CONDITIONS (NCOMP) = 126

COMPONENT DATA (LAMBDA AND TAU)
(NON-POSITIVE TAU DENOTES NON-REPAIR)
(NON-POSITIVE LAMBDA DENOTES INHIBIT CONDITION)

| COMPONENT INDEX | LAMBDA | TAU |
|---|---|---|
| 1 | 1.14000000E-05 | 2.16000000E+03 |
| 2 | 1.14000000E-06 | 2.16000000E+03 |
| 3 | 1.14000000E-05 | 2.16000000E+03 |
| 4 | 1.14000000E-06 | 2.16000000E+03 |
| 5 | 1.14000000E-05 | 2.16000000E+03 |
| 6 | 1.14000000E-06 | 2.16000000E+03 |
| 7 | 1.14000000E-05 | 2.16000000E+03 |
| 8 | 1.14000000E-06 | 2.16000000E+03 |
| 9 | 1.14000000E-05 | 2.16000000E+03 |
| 10 | 1.14000000E-06 | 2.16000000E+03 |
| 11 | 1.14000000E-05 | 2.16000000E+03 |
| 12 | 1.14000000E-06 | 2.16000000E+03 |
| 13 | 1.14000000E-05 | 2.16000000E+03 |
| 14 | 1.14000000E-06 | 2.16000000E+03 |
| 15 | 1.14000000E-05 | 2.16000000E+03 |
| 16 | 1.14000000E-06 | 2.16000000E+03 |
| 17 | 1.14000000E-05 | 2.16000000E+03 |
| 18 | 1.14000000E-05 | 2.16000000E+03 |
| 19 | 1.14000000E-05 | 2.16000000E+03 |
| 20 | 1.14000000E-05 | 2.16000000E+03 |
| 21 | 1.14000000E-05 | 2.16000000E+03 |
| 22 | 1.14000000E-05 | 2.16000000E+03 |
| 23 | 1.14000000E-05 | 2.16000000E+03 |
| 24 | 1.14000000E-05 | 2.16000000E+03 |
| 25 | 1.14000000E-05 | 2.16000000E+03 |
| 26 | 1.14000000E-05 | 2.16000000E+03 |
| 27 | 1.14000000E-05 | 2.16000000E+03 |
| 28 | 1.14000000E-05 | 2.16000000E+03 |
| 29 | 1.14000000E-05 | 2.16000000E+03 |
| 30 | 1.14000000E-05 | 2.16000000E+03 |
| 31 | 1.14000000E-05 | 2.16000000E+03 |
| 32 | 1.14000000E-05 | 2.16000000E+03 |
| 33 | 1.14000000E-06 | 2.16000000E+03 |
| 34 | 1.14000000E-06 | 2.16000000E+03 |
| 35 | 1.14000000E-06 | 2.16000000E+03 |
| 36 | 1.14000000E-06 | 2.16000000E+03 |
| 37 | 1.14000000E-06 | 2.16000000E+03 |
| 38 | 1.14000000E-05 | 2.16000000E+03 |
| 39 | 1.14000000E-06 | 2.16000000E+03 |
| 40 | 1.14000000E-06 | 2.16000000E+03 |
| 41 | 1.14000000E-07 | 2.16000000E+03 |
| 42 | 1.14000000E-06 | 2.16000000E+03 |

| | | |
|---|---|---|
| 44 | 1.14000000E-05 | 2.16000000E+03 |
| 45 | 1.14000000E-07 | 2.16000000E+03 |
| 46 | 1.14000000E-07 | 2.16000000E+03 |
| 47 | 1.14000000E-05 | 2.16000000E+03 |
| 48 | 1.14000000E-06 | 2.16000000E+03 |
| 49 | 1.14000000E-05 | 2.16000000E+03 |
| 50 | 1.14000000E-06 | 2.16000000E+03 |
| 51 | 1.14000000E-05 | 2.16000000E+03 |
| 52 | 1.14000000E-06 | 2.16000000E+03 |
| 53 | 1.14000000E-05 | 2.16000000E+03 |
| 54 | 1.14000000E-06 | 2.16000000E+03 |
| 55 | 1.14000000E-05 | 2.16000000E+03 |
| 56 | 1.14000000E-06 | 2.16000000E+03 |
| 57 | 1.14000000E-05 | 2.16000000E+03 |
| 58 | 1.14000000E-06 | 2.16000000E+03 |
| 59 | 1.14000000E-05 | 2.16000000E+03 |
| 60 | 1.14000000E-06 | 2.16000000E+03 |
| 61 | 1.14000000E-05 | 2.16000000E+03 |
| 62 | 1.14000000E-06 | 2.16000000E+03 |
| 63 | 1.14000000E-05 | 2.16000000E+03 |
| 64 | 1.14000000E-05 | 2.16000000E+03 |
| 65 | 1.14000000E-05 | 2.16000000E+03 |
| 66 | 1.14000000E-05 | 2.16000000E+03 |
| 67 | 1.14000000E-05 | 2.16000000E+03 |
| 68 | 1.14000000E-05 | 2.16000000E+03 |
| 69 | 1.14000000E-05 | 2.16000000E+03 |
| 70 | 1.14000000E-05 | 2.16000000E+03 |
| 71 | 1.14000000E-05 | 2.16000000E+03 |
| 72 | 1.14000000E-05 | 2.16000000E+03 |
| 73 | 1.14000000E-05 | 2.16000000E+03 |
| 74 | 1.14000000E-05 | 2.16000000E+03 |
| 75 | 1.14000000E-05 | 2.16000000E+03 |
| 76 | 1.14000000E-05 | 2.16000000E+03 |
| 77 | 1.14000000E-05 | 2.16000000E+03 |
| 78 | 1.14000000E-05 | 2.16000000E+03 |
| 79 | 1.14000000E-06 | 2.16000000E+03 |
| 80 | 1.14000000E-06 | 2.16000000E+03 |
| 81 | 1.14000000E-06 | 2.16000000E+03 |
| 82 | 1.14000000E-06 | 2.16000000E+03 |
| 83 | 1.14000000E-06 | 2.16000000E+03 |
| 84 | 1.14000000E-05 | 2.16000000E+03 |
| 85 | 1.14000000E-06 | 2.16000000E+03 |
| 86 | 1.14000000E-06 | 2.16000000E+03 |
| 87 | 1.14000000E-07 | 2.16000000E+03 |
| 88 | 1.14000000E-06 | 2.16000000E+03 |
| 89 | 1.14000000E-06 | 2.16000000E+03 |
| 90 | 1.14000000E-05 | 2.16000000E+03 |
| 91 | 1.14000000E-07 | 2.16000000E+03 |
| 92 | 1.14000000E-07 | 2.16000000E+03 |
| 93 | 1.14000000E-05 | 2.16000000E+03 |
| 94 | 1.14000000E-05 | 2.16000000E+03 |
| 95 | 1.14000000E-05 | 2.16000000E+03 |
| 96 | 1.14000000E-05 | 2.16000000E+03 |
| 97 | 1.14000000E-06 | 2.16000000E+03 |
| 98 | 1.14000000E-06 | 2.16000000E+03 |
| 99 | 1.14000000E-06 | 2.16000000E+03 |
| 100 | 1.14000000E-06 | 2.16000000E+03 |
| 101 | 1.14000000E-06 | 2.16000000E+03 |
| 102 | 1.14000000E-05 | 2.16000000E+03 |
| 103 | 1.14000000E-05 | 2.16000000E+03 |
| 104 | 1.14000000E-05 | 2.16000000E+03 |
| 105 | 1.14000000E-05 | 2.16000000E+03 |
| 106 | 1.14000000E-06 | 2.16000000E+03 |
| 107 | 1.14000000E-06 | 2.16000000E+03 |
| 108 | 1.14000000E-06 | 2.16000000E+03 |

| | | |
|---|---|---|
| [illegible] | [illegible] | [illegible] |
| 110 | 1.14000000E-06 | 2.16000000E+03 |
| 111 | 1.14000000E-05 | 2.16000000E+03 |
| 112 | 1.14000000E-05 | 2.16000000E+03 |
| 113 | 1.14000000E-05 | 2.16000000E+03 |
| 114 | 1.14000000E-05 | 2.16000000E+03 |
| 115 | 1.14000000E-05 | 2.16000000E+03 |
| 116 | 1.14000000E-05 | 2.16000000E+03 |
| 117 | 1.14000000E-05 | 2.16000000E+03 |
| 118 | 1.14000000E-05 | 2.16000000E+03 |
| 119 | 1.14000000E-05 | 2.16000000E+03 |
| 120 | 1.14000000E-05 | 2.16000000E+03 |
| 121 | 1.14000000E-06 | 2.16000000E+03 |
| 122 | 1.14000000E-06 | 2.16000000E+03 |
| 123 | 1.14000000E-07 | 2.16000000E+03 |
| 124 | 1.14000000E-07 | 2.16000000E+03 |
| 125 | 1.14000000E-07 | 2.16000000E+03 |
| 126 | 1.14000000E-07 | 2.16000000E+03 |

BRACKET FLAG (ISTOP). IF ISTOP=2 SYSTEM INFORMATION IS OBTAINED FROM BRACKETING. IF ISTOP=1 IT IS NOT.
FOR THIS PROBLEM ISTOP = 1

NO. OF TIME POINTS (NTPT) = 5
PRINT OUT MULTIPLE (NOUT) = 1
MESH SIZE (DELTA) = 2.16000000E+03 HOURS

SET FLAG (IPATH). IF IPATH=1 MINIMAL CUT SETS ARE USED. IF IPATH=2 MINIMAL PATH SETS ARE USED.
FOR THIS PROBLEM IPATH = 1

NO. OF SETS (NCUT) = 144

SET INFORMATION

SET NO. 1. WITH COMPONENTS - 87 41

SET NO. 2. WITH COMPONENTS - 87 42

SET NO. 3. WITH COMPONENTS - 87 43

SET NO. 4. WITH COMPONENTS - 87 44

SET NO. 5. WITH COMPONENTS - 87 45

SET NO. 6. WITH COMPONENTS - 87 46

SET NO. 7. WITH COMPONENTS - 88 41

SET NO. 8. WITH COMPONENTS - 88 42

SET NO. 9. WITH COMPONENTS - 88 43

SET NO. 10. WITH COMPONENTS - 88 44

```
SET NO.  11. WITH COMPONENTS -   88   45
SET NO.  12. WITH COMPONENTS -   88   46
SET NO.  13. WITH COMPONENTS -   89   41
SET NO.  14. WITH COMPONENTS -   89   42
SET NO.  15. WITH COMPONENTS -   89   43
SET NO.  16. WITH COMPONENTS -   89   44
SET NO.  17. WITH COMPONENTS -   89   45
SET NO.  18. WITH COMPONENTS -   89   46
SET NO.  19. WITH COMPONENTS -   90   41
SET NO.  20. WITH COMPONENTS -   90   42
SET NO.  21. WITH COMPONENTS -   90   43
SET NO.  22. WITH COMPONENTS -   90   44
SET NO.  23. WITH COMPONENTS -   90   45
SET NO.  24. WITH COMPONENTS -   90   46
SET NO.  25. WITH COMPONENTS -   91   41
SET NO.  26. WITH COMPONENTS -   91   42
SET NO.  27. WITH COMPONENTS -   91   43
SET NO.  28. WITH COMPONENTS -   91   44
SET NO.  29. WITH COMPONENTS -   91   45
SET NO.  30. WITH COMPONENTS -   91   46
SET NO.  31. WITH COMPONENTS -   92   41
SET NO.  32. WITH COMPONENTS -   92   42
SET NO.  33. WITH COMPONENTS -   92   43
SET NO.  34. WITH COMPONENTS -   92   44
SET NO.  35. WITH COMPONENTS -   92   45
SET NO.  36. WITH COMPONENTS -   92   46
SET NO.  37. WITH COMPONENTS -  101   87
SET NO.  38. WITH COMPONENTS -  101   88
SET NO.  39. WITH COMPONENTS -  101   89
SET NO.  40. WITH COMPONENTS -  101   90
SET NO.  41. WITH COMPONENTS -  101   91
SET NO.  42. WITH COMPONENTS -  101   92
SET NO.  43. WITH COMPONENTS -  110   41
```

```
SET NO. 44. WITH COMPONENTS - 110 42
SET NO. 45. WITH COMPONENTS - 110 43
SET NO. 46. WITH COMPONENTS - 110 44
SET NO. 47. WITH COMPONENTS - 110 45
SET NO. 48. WITH COMPONENTS - 110 46
SET NO. 49. WITH COMPONENTS - 110 101
SET NO. 50. WITH COMPONENTS - 111 87
SET NO. 51. WITH COMPONENTS - 111 88
SET NO. 52. WITH COMPONENTS - 111 89
SET NO. 53. WITH COMPONENTS - 111 90
SET NO. 54. WITH COMPONENTS - 111 91
SET NO. 55. WITH COMPONENTS - 111 92
SET NO. 56. WITH COMPONENTS - 111 110
SET NO. 57. WITH COMPONENTS - 113 41
SET NO. 58. WITH COMPONENTS - 113 42
SET NO. 59. WITH COMPONENTS - 113 43
SET NO. 60. WITH COMPONENTS - 113 44
SET NO. 61. WITH COMPONENTS - 113 45
SET NO. 62. WITH COMPONENTS - 113 46
SET NO. 63. WITH COMPONENTS - 113 101
SET NO. 64. WITH COMPONENTS - 113 111
SET NO. 65. WITH COMPONENTS - 115 87
SET NO. 66. WITH COMPONENTS - 115 88
SET NO. 67. WITH COMPONENTS - 115 89
SET NO. 68. WITH COMPONENTS - 115 90
SET NO. 69. WITH COMPONENTS - 115 91
SET NO. 70. WITH COMPONENTS - 115 92
SET NO. 71. WITH COMPONENTS - 115 110
SET NO. 72. WITH COMPONENTS - 115 113
SET NO. 73. WITH COMPONENTS - 118 41
SET NO. 74. WITH COMPONENTS - 118 42
SET NO. 75. WITH COMPONENTS - 118 43
SET NO. 76. WITH COMPONENTS - 118 44
```

```
SET NO.  77. WITH COMPONENTS -  118   45
SET NO.  78. WITH COMPONENTS -  118   46
SET NO.  79. WITH COMPONENTS -  118  101
SET NO.  80. WITH COMPONENTS -  118  111
SET NO.  81. WITH COMPONENTS -  118  115
SET NO.  82. WITH COMPONENTS -  121   87
SET NO.  83. WITH COMPONENTS -  121   88
SET NO.  84. WITH COMPONENTS -  121   89
SET NO.  85. WITH COMPONENTS -  121   90
SET NO.  86. WITH COMPONENTS -  121   91
SET NO.  87. WITH COMPONENTS -  121   92
SET NO.  88. WITH COMPONENTS -  121  110
SET NO.  89. WITH COMPONENTS -  121  113
SET NO.  90. WITH COMPONENTS -  121  118
SET NO.  91. WITH COMPONENTS -  122   41
SET NO.  92. WITH COMPONENTS -  122   42
SET NO.  93. WITH COMPONENTS -  122   43
SET NO.  94. WITH COMPONENTS -  122   44
SET NO.  95. WITH COMPONENTS -  122   45
SET NO.  96. WITH COMPONENTS -  122   46
SET NO.  97. WITH COMPONENTS -  122  101
SET NO.  98. WITH COMPONENTS -  122  111
SET NO.  99. WITH COMPONENTS -  122  115
SET NO. 100. WITH COMPONENTS -  122  121
SET NO. 101. WITH COMPONENTS -  123   87
SET NO. 102. WITH COMPONENTS -  123   88
SET NO. 103. WITH COMPONENTS -  123   89
SET NO. 104. WITH COMPONENTS -  123   90
SET NO. 105. WITH COMPONENTS -  123   91
SET NO. 106. WITH COMPONENTS -  123   92
SET NO. 107. WITH COMPONENTS -  123  110
SET NO. 108. WITH COMPONENTS -  123  113
SET NO. 109. WITH COMPONENTS -  123  118
```

SET NO. 110, WITH COMPONENTS - 123 122
SET NO. 111, WITH COMPONENTS - 124 41
SET NO. 112, WITH COMPONENTS - 124 42
SET NO. 113, WITH COMPONENTS - 124 43
SET NO. 114, WITH COMPONENTS - 124 44
SET NO. 115, WITH COMPONENTS - 124 45
SET NO. 116, WITH COMPONENTS - 124 46
SET NO. 117, WITH COMPONENTS - 124 101
SET NO. 118, WITH COMPONENTS - 124 111
SET NO. 119, WITH COMPONENTS - 124 115
SET NO. 120, WITH COMPONENTS - 124 121
SET NO. 121, WITH COMPONENTS - 124 123
SET NO. 122, WITH COMPONENTS - 125 87
SET NO. 123, WITH COMPONENTS - 125 88
SET NO. 124, WITH COMPONENTS - 125 89
SET NO. 125, WITH COMPONENTS - 125 90
SET NO. 126, WITH COMPONENTS - 125 91
SET NO. 127, WITH COMPONENTS - 125 92
SET NO. 128, WITH COMPONENTS - 125 110
SET NO. 129, WITH COMPONENTS - 125 113
SET NO. 130, WITH COMPONENTS - 125 118
SET NO. 131, WITH COMPONENTS - 125 122
SET NO. 132, WITH COMPONENTS - 125 124
SET NO. 133, WITH COMPONENTS - 126 41
SET NO. 134, WITH COMPONENTS - 126 42
SET NO. 135, WITH COMPONENTS - 126 43
SET NO. 136, WITH COMPONENTS - 126 44
SET NO. 137, WITH COMPONENTS - 126 45
SET NO. 138, WITH COMPONENTS - 126 46
SET NO. 139, WITH COMPONENTS - 126 101
SET NO. 140, WITH COMPONENTS - 126 111
SET NO. 141, WITH COMPONENTS - 126 115
SET NO. 142, WITH COMPONENTS - 126 121

SET NO. 143, WITH COMPONENTS - 126 123

SET NO. 144, WITH COMPONENTS - 126 125

COMPONENT AND INHIBIT INFORMATION

## MINIMAL SET INFORMATION

### CHARACTERISTICS FOR SET NO. = 1

| T (HOURS) | Q | W | L | WSUM | FSUM |
|---|---|---|---|---|---|
| 0. | 0. | 0. | 0. | 0. | 0. |
| 2.1600000E+03 | 6.0619209E-08 | 5.6121987E-11 | 5.6121990E-11 | 6.0611746E-08 | 6.0611747E-08 |
| 4.3200000E+03 | 6.0604286E-08 | 5.6115080E-11 | 5.6115084E-11 | 1.8182778E-07 | 1.8182777E-07 |
| 6.4800000E+03 | 6.0604288E-08 | 5.6115081E-11 | 5.6115084E-11 | 3.0303635E-07 | 3.0303633E-07 |
| 8.6400000E+03 | 6.0604288E-08 | 5.6115081E-11 | 5.6115084E-11 | 4.2424493E-07 | 4.2424487E-07 |

### CHARACTERISTICS FOR SET NO. = 2

| T (HOURS) | Q | W | L | WSUM | FSUM |
|---|---|---|---|---|---|
| 0. | 0. | 0. | 0. | 0. | 0. |
| 2.1600000E+03 | 6.0552091E-07 | 5.6028799E-10 | 5.6028833E-10 | 6.0511103E-07 | 6.0511121E-07 |
| 4.3200000E+03 | 6.0470247E-07 | 5.5990998E-10 | 5.5991032E-10 | 1.8149248E-06 | 1.8149243E-06 |
| 6.4800000E+03 | 6.0470309E-07 | 5.5991027E-10 | 5.5991060E-10 | 3.0243307E-06 | 3.0243280E-06 |
| 8.6400000E+03 | 6.0470309E-07 | 5.5991027E-10 | 5.5991060E-10 | 4.2337369E-06 | 4.2337305E-06 |

### CHARACTERISTICS FOR SET NO. = 3

| T (HOURS) | Q | W | L | WSUM | FSUM |
|---|---|---|---|---|---|
| 0. | 0. | 0. | 0. | 0. | 0. |
| 2.1600000E+03 | 6.0552091E-07 | 5.6028799E-10 | 5.6028833E-10 | 6.0511103E-07 | 6.0511121E-07 |
| 4.3200000E+03 | 6.0470247E-07 | 5.5990998E-10 | 5.5991032E-10 | 1.8149248E-06 | 1.8149243E-06 |
| 6.4800000E+03 | 6.0470309E-07 | 5.5991027E-10 | 5.5991060E-10 | 3.0243307E-06 | 3.0243280E-06 |
| 8.6400000E+03 | 6.0470309E-07 | 5.5991027E-10 | 5.5991060E-10 | 4.2337369E-06 | 4.2337305E-06 |

### CHARACTERISTICS FOR SET NO. = 4

| T (HOURS) | Q | W | L | WSUM | FSUM |
|---|---|---|---|---|---|
| 0. | 0. | 0. | 0. | 0. | 0. |
| 2.1600000E+03 | 5.9886327E-06 | 5.5106938E-09 | 5.5107268E-09 | 5.9515493E-06 | 5.9515472E-06 |
| 4.3200000E+03 | 5.9156705E-06 | 5.4777426E-09 | 5.4777750E-09 | 1.7819061E-05 | 1.7819008E-05 |
| 6.4800000E+03 | 5.9162429E-06 | 5.4780011E-09 | 5.4780335E-09 | 2.9651264E-05 | 2.9651001E-05 |
| 8.6400000E+03 | 5.9162396E-06 | 5.4779996E-09 | 5.4780320E-09 | 4.1483745E-05 | 4.1483130E-05 |

### CHARACTERISTICS FOR SET NO. = 5

| T (HOURS) | Q | W | L | WSUM | FSUM |
|---|---|---|---|---|---|
| 0. | 0. | 0. | 0. | 0. | 0. |
| 2.1600000E+03 | 6.0619209E-08 | 5.6121987E-11 | 5.6121990E-11 | 6.0611746E-08 | 6.0611747E-08 |
| 4.3200000E+03 | 6.0604286E-08 | 5.6115080E-11 | 5.6115084E-11 | 1.8182778E-07 | 1.8182777E-07 |
| 6.4800000E+03 | 6.0604288E-08 | 5.6115081E-11 | 5.6115084E-11 | 3.0303635E-07 | 3.0303633E-07 |
| 8.6400000E+03 | 6.0604288E-08 | 5.6115081E-11 | 5.6115084E-11 | 4.2424493E-07 | 4.2424487E-07 |

### CHARACTERISTICS FOR SET NO. = 6

| T (HOURS) | Q | W | L | WSUM | FSUM |
|---|---|---|---|---|---|
| 0. | 0. | 0. | 0. | 0. | 0. |
| 2.1600000E+03 | 6.0619209E-08 | 5.6121987E-11 | 5.6121990E-11 | 6.0611746E-08 | 6.0611747E-08 |
| 4.3200000E+03 | 6.0604286E-08 | 5.6115080E-11 | 5.6115084E-11 | 1.8182778E-07 | 1.8182777E-07 |

| | | | | | |
|---|---|---|---|---|---|
| 8.6400000E+03 | 6.0604288E-08 | 5.6115081E-11 | 5.6115084E-11 | 4.2424493E-07 | 4.2424487E-07 |

CHARACTERISTICS FOR SET NO. = 7

| T (HOURS) | Q | W | L | WSUM | FSUM |
|---|---|---|---|---|---|
| 0. | 0. | 0. | 0. | 0. | 0. |
| 2.1600000E+03 | 6.0552091E-07 | 5.6028799E-10 | 5.6028833E-10 | 6.0511103E-07 | 6.0511121E-07 |
| 4.3200000E+03 | 6.0470247E-07 | 5.5990998E-10 | 5.5991032E-10 | 1.8149248E-06 | 1.8149243E-06 |
| 6.4800000E+03 | 6.0470309E-07 | 5.5991027E-10 | 5.5991060E-10 | 3.0243307E-06 | 3.0243280E-06 |
| 8.6400000E+03 | 6.0470309E-07 | 5.5991027E-10 | 5.5991060E-10 | 4.2337369E-06 | 4.2337305E-06 |

CHARACTERISTICS FOR SET NO. = 8

| T (HOURS) | Q | W | L | WSUM | FSUM |
|---|---|---|---|---|---|
| 0. | 0. | 0. | 0. | 0. | 0. |
| 2.1600000E+03 | 6.0485046E-06 | 5.5935748E-09 | 5.5936086E-09 | 6.0410608E-06 | 6.0410791E-06 |
| 4.3200000E+03 | 6.0336505E-06 | 5.5867190E-09 | 5.5867527E-09 | 1.8115778E-05 | 1.8115723E-05 |
| 6.4800000E+03 | 6.0336626E-06 | 5.5867246E-09 | 5.5867583E-09 | 3.0183097E-05 | 3.0182824E-05 |
| 8.6400000E+03 | 6.0336626E-06 | 5.5867246E-09 | 5.5867583E-09 | 4.2250422E-05 | 4.2249785E-05 |

CHARACTERISTICS FOR SET NO. = 9

| T (HOURS) | Q | W | L | WSUM | FSUM |
|---|---|---|---|---|---|
| 0. | 0. | 0. | 0. | 0. | 0. |
| 2.1600000E+03 | 6.0485046E-06 | 5.5935748E-09 | 5.5936086E-09 | 6.0410608E-06 | 6.0410791E-06 |
| 4.3200000E+03 | 6.0336505E-06 | 5.5867190E-09 | 5.5867527E-09 | 1.8115778E-05 | 1.8115723E-05 |
| 6.4800000E+03 | 6.0336626E-06 | 5.5867246E-09 | 5.5867583E-09 | 3.0183097E-05 | 3.0182824E-05 |
| 8.6400000E+03 | 6.0336626E-06 | 5.5867246E-09 | 5.5867583E-09 | 4.2250422E-05 | 4.2249785E-05 |



CHARACTERISTICS FOR SET NO. = 10

| T (HOURS) | Q | W | L | WSUM | FSUM |
|---|---|---|---|---|---|
| 0. | 0. | 0. | 0. | 0. | 0. |
| 2.1600000E+03 | 5.9820019E-05 | 5.5015249E-08 | 5.5018540E-08 | 5.9416469E-05 | 5.9418258E-05 |
| 4.3200000E+03 | 5.9025868E-05 | 5.4656302E-08 | 5.4659528E-08 | 1.7786174E-04 | 1.7785652E-04 |
| 6.4800000E+03 | 5.9031638E-05 | 5.4658908E-08 | 5.4662135E-08 | 2.9592217E-04 | 2.9589595E-04 |
| 8.6400000E+03 | 5.9031604E-05 | 5.4658893E-08 | 5.4662120E-08 | 4.1398540E-04 | 4.1392424E-04 |

CHARACTERISTICS FOR SET NO. = 11

| T (HOURS) | Q | W | L | WSUM | FSUM |
|---|---|---|---|---|---|
| 0. | 0. | 0. | 0. | 0. | 0. |
| 2.1600000E+03 | 6.0552091E-07 | 5.6028799E-10 | 5.6028833E-10 | 6.0511103E-07 | 6.0511121E-07 |
| 4.3200000E+03 | 6.0470247E-07 | 5.5990998E-10 | 5.5991032E-10 | 1.8149248E-06 | 1.8149243E-06 |
| 6.4800000E+03 | 6.0470309E-07 | 5.5991027E-10 | 5.5991060E-10 | 3.0243307E-06 | 3.0243280E-06 |
| 8.6400000E+03 | 6.0470309E-07 | 5.5991027E-10 | 5.5991060E-10 | 4.2337369E-06 | 4.2337305E-06 |

CHARACTERISTICS FOR SET NO. = 12

| T (HOURS) | Q | W | L | WSUM | FSUM |
|---|---|---|---|---|---|
| 0. | 0. | 0. | 0. | 0. | 0. |
| 2.1600000E+03 | 6.0552091E-07 | 5.6028799E-10 | 5.6028833E-10 | 6.0511103E-07 | 6.0511121E-07 |
| 4.3200000E+03 | 6.0470247E-07 | 5.5990998E-10 | 5.5991032E-10 | 1.8149248E-06 | 1.8149243E-06 |

SYSTEM INFORMATION-UPPER BOUNDS

DIFFERENTIAL CHARACTERISTICS-UPPER BOUNDS

| T (HOURS) | Q | W | L |
|---|---|---|---|
| 0. | 0. | 0. | 0. |
| 2.16000000E+03 | 7.03918676E-03 | 6.46873917E-06 | 6.51459663E-06 |
| 4.32000000E+03 | 6.89095697E-03 | 6.40171960E-06 | 6.44613967E-06 |
| 6.48000000E+03 | 6.89211104E-03 | 6.40224413E-06 | 6.44667533E-06 |
| 8.64000000E+03 | 6.89210437E-03 | 6.40224109E-06 | 6.44667223E-06 |

INTEGRAL CHARACTERISTICS-UPPER BOUNDS

| T (HOURS) | WSUM | FSUM |
|---|---|---|
| 2.16000000E+03 | 6.98623830E-03 | 7.01107132E-03 |
| 4.32000000E+03 | 2.08863338E-02 | 2.08137012E-02 |
| 6.48000000E+03 | 3.47146146E-02 | 3.43536410E-02 |
| 8.64000000E+03 | 4.85434586E-02 | 4.77069016E-02 |

*****CONCLUSION OF OUTPUT FROM KITT-1*****

## DISTRIBUTION LIST

| | COPY NO. |
|---|---|
| Commander<br>US Army Materiel Command<br>ATTN: AMCRD, AMCRD-EA, AMCRD-ES, AMCDL, AMCIS-MD, AMCMM-S, AMCPA-E, AMCSF, AMCRP-I<br>5001 Eisenhower Avenue<br>Alexandria, VA 22333 | 1-9 |
| Commander<br>USAMC Installations & Services Directorate<br>ATTN: AMCIS-RI-IU<br>Rock Island, IL 61201 | 10 |
| Commander<br>US Army Armament Command<br>ATTN: AMSAR-PPI-C | 11-12 |
| AMSAR-RD | 13 |
| AMSAR-ISE | 14 |
| AMSAR-SC | 15 |
| AMSAR-EN | 16 |
| AMSAR-PPW<br>Rock Island, IL 61201 | 17 |
| Project Manager for Munition Production<br>Base Modernization & Expansion<br>US Army Materiel Command<br>ATTN: AMCPM-PBM-EC | 18 |
| AMCPM-PBM-EB<br>Dover, New Jersey 07801 | 19 |
| Department of the Army<br>Ofc Ch Research, Development and Acquisition<br>ATTN: DAMA-CSM-P<br>Washington, D. C. 20310 | 20 |
| Commander<br>US Army Procurement Equipment Agency<br>ATTN: AMX-PE-MT<br>Rock Island, IL 61201 | 21 |
| Department of the Army<br>ATTN: DAEN-ZCE<br>Washington, D. C. 20310 | 22 |

| | COPY NO. |
|---|---|
| Commander<br>Edgewood Arsenal<br>ATTN: SAREA-TD-P<br>Aberdeen Proving Grounds, MD 21010 | 23 |
| Commander<br>Frankford Arsenal<br>ATTN: SARFA-MMT-C<br>Philadelphia, PA 19137 | 24 |
| Defense Contract Administration Services<br>1610 S. Federal Building<br>100 Liberty Avenue<br>Pittsburgh, PA 15222 | 25-26 |
| Defense Documentation Center<br>Cameron Station<br>Alexandria, VA 22314 | 27-38 |
| Commander<br>US Army Construction Engineeering<br>Research Laboratory<br>ATTN: CERL-ER<br>Champaign, IL 61820 | 39 |
| Office Chief of Engineers<br>ATTN: DAEN-MCZ-E<br>Washington, D. C. 20314 | 40-41 |
| US Army Engr District, NEW YORK<br>ATTN: Construction Div<br>26 Federal Plaza<br>New York, NY 10007 | 42 |
| US Army Engr District, BALTIMORE<br>ATTN: Construction Div<br>P. O. Box 1715<br>Baltimore, MD 21203 | 43 |
| US Army Engr District, NORFOLK<br>ATTN: Construction Div<br>803 Front St<br>Norfolk, VA 23510 | 44 |
| US Army Engr District, MOBILE<br>ATTN: Construction Div<br>P. O. Box 2288<br>Mobile, AL 36628 | 45 |

| | COPY NO. |
|---|---|
| US Army Engr. District, FORT WORTH<br>ATTN: Construction Div<br>P. O. Box 17300<br>Ft. Worth, TX 76102 | 46 |
| US Army Engr District OMAHA<br>ATTN: Construction Div<br>6014 USPO & Courthouse<br>215 North 17th Street<br>Omaha, NB 68102 | 47 |
| US Army Engr District, KANSAS CITY<br>ATTN: Construction Div<br>700 Federal Bldg.<br>Kansas City, MO 64106 | 48-49 |
| US Army Engr District, SACREMENTO<br>ATTN: Construction Div<br>650 Capitol Mall<br>Sacramento, CA 95814 | 50 |
| US Army Engr District, HUNTSVILLE<br>ATTN: ConstructionDiv<br>P. O. Box 1600 West Station<br>Huntsville, AL 35807 | 51 |
| Commander<br>US Army Environmental Hygiene Agency<br>ATTN: USAEHA-E<br>Aberdeen Proving Ground, MD 21010 | 52-53 |
| Commander<br>Badger Army Ammunition Plant<br>ATTN: SARBA-CE<br>Baraboo, WI 53913 | 54 |
| Commander<br>Cornhusker Army Ammunition Plant<br>ATTN: SARCO-E<br>Grand Island, NB 68801 | 55 |
| Commander<br>Holston Army Ammunition Plant<br>ATTN: SARHO-E<br>Kingsport, TN 37662 | 56 |
| Commander<br>Indiana Army Ammunition Plant<br>ATTN: SARIN-OR<br>Charlestown, IN 47111 | 57 |

| | COPY NO. |
|---|---|
| Commander<br>Naval Weapons Support Center<br>ATTN: Code 5042, Mr. C. W. Gilliam<br>Crane, IN 47522 | 58 |
| Commander<br>Iowa Army Ammunition Plant<br>ATTN: SARIO-A<br>Burlington, IA 52601 | 59 |
| Commander<br>Joliet Army Ammunition Plant<br>ATTN: SARJO-SS-E<br>Joliet, IL 60436 | 60 |
| Commander<br>Kansas Army Ammunition Plant<br>ATTN: SARKA-CE<br>Parsons, KS 67537 | 61 |
| Commander<br>Lone Star Army Ammunition Plant<br>ATTN: SARLS-IE<br>Texarkana, TX 75501 | 62 |
| Commander<br>Longhorn Army Ammunition Plant<br>ATTN: SARLO-O<br>Marshall, TX 75670 | 63 |
| Commander<br>Louisiana Army Ammunition Plant<br>ATTN: SARLA-S<br>Shreveport, LA 71102 | 64 |
| Commander<br>Milan Army Ammunition Plant<br>ATTN: SARMI-S<br>Milan, TN 38358 | 65 |
| Commander<br>Newport Army Ammunition Plant<br>ATTN: SARNE-S<br>Newport, IN 47966 | 66 |
| Commander<br>Pine Bluff Arsenal<br>ATTN: SARPB-ETA<br>Pine Bluff, AR 71601 | 67 |

| | COPY NO. |
|---|---|
| Commander<br>Radford Army Ammunition Plant<br>ATTN: SARRA-IE<br>Radford, VA 24141 | 68 |
| Commander<br>Ravenna Army Ammunition Plant<br>Ravenna, OH 44266 | 69 |
| Commander<br>Sunflower Army Ammunition Plant<br>ATTN: SARSU-O<br>Lawrence, KS 66044 | 70 |
| Commander<br>Volunteer Army Ammunition Plant<br>ATTN: SARVO-T<br>Chattanooga, TN 34701 | 71 |
| Dr. John A. Brown<br>P. O. Box 145<br>Berkeley Heights, N. J. 07922 | 72 |
| Dr. John W. Dawson<br>Rt. 8 Box 274<br>Durham, NC 27704 | 73 |
| Army Logistics Management Center<br>Environmental Management<br>ATTN: LCDR J. C. Bolander<br>Fort Lee, VA 23801 | 74-75 |
| Commander<br>Picatinny Arsenal | |
| ATTN: SARPA-CO | 76 |
| SARPA-MT | 77 |
| SARPA-MT-S | 78-87 |
| SARPA-MT-T | 88 |
| SARPA-TS | 89-93 |
| SARPA-ND | 94 |
| SARPA-ND-C | 95-99 |
| SARPA-ND-S | 100 |
| SARPA-ND-T-A | 101-104 |